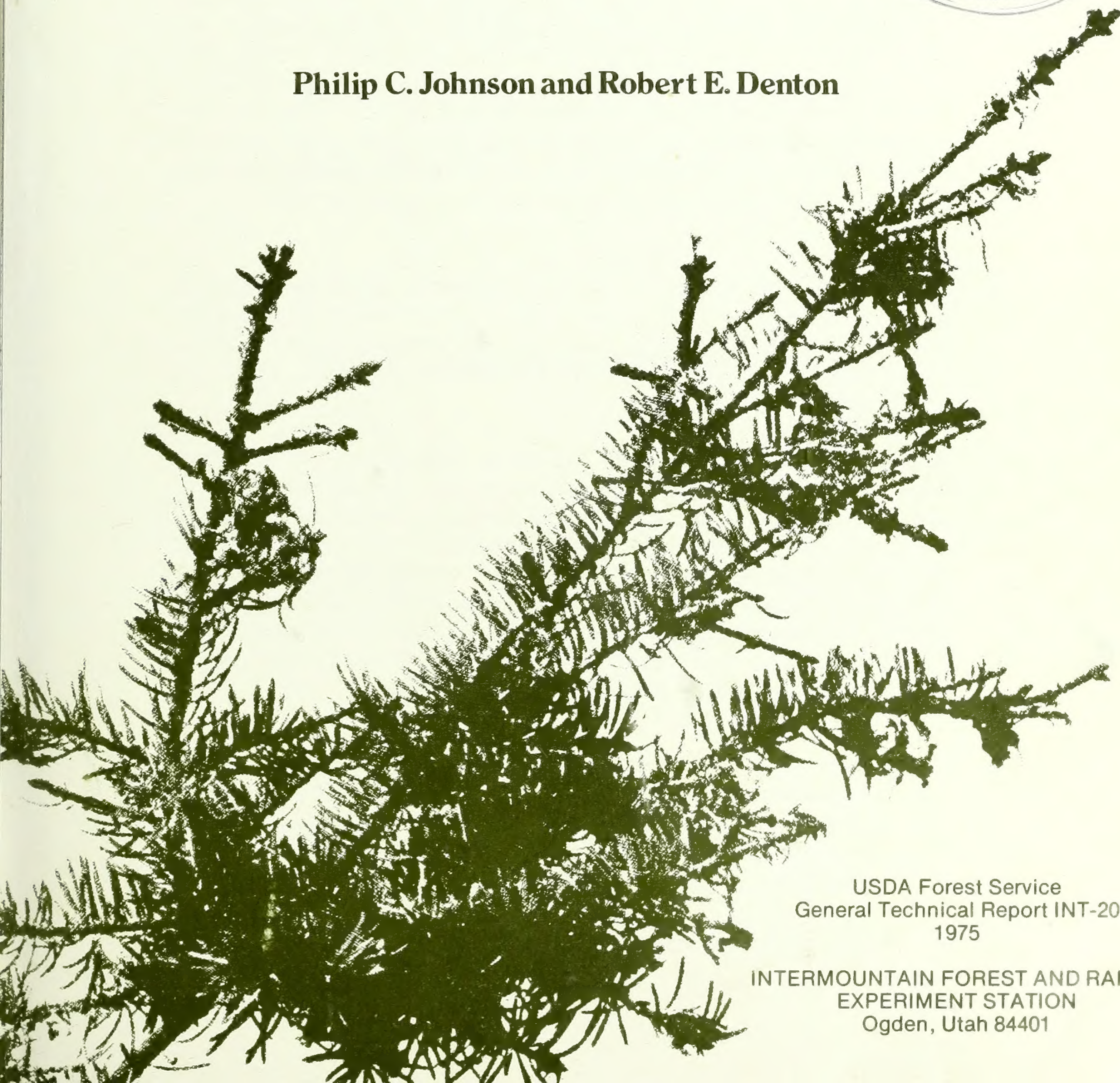
OUTBREAKS OF THE WESTERN SPRUCE BUDWORM IN THE AMERICAN NORTHERN ROCKY MOUNTAIN AREA FROM 1922 THROUGH 1971

Philip C. Johnson and Robert E. Denton



USDA Forest Service
General Technical Report INT-20
1975

INTERMOUNTAIN FOREST AND RANGE
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Unpublished reports listed in this publication are permanently filed at the School of Forestry Library of the University of Montana for availability to future research workers on the western spruce budworm.

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ABSTRACT

The western spruce budworm has severely damaged more than 15 million acres of publicly and privately owned coniferous forests chiefly in the American northern Rocky Mountain area. Abundant information about behavior of the budworm, characteristics of outbreaks of its populations, and kinds and severity of damage is available from National Forest ranger district annual reports of insect conditions, which were started in 1925, and from later reports of damage surveys made by forest entomologists since 1948. The first report of an outbreak of this insect appeared in January 1922. Numerous outbreaks have appeared since then, chiefly in forests of Montana and Idaho but also in Utah and Wyoming. In a few ranger districts in Montana infestation has continued until now, but in many locations the budworm outbreaks have continued for less than 5 years.

For about 30 years following the first reported outbreak, forest entomologists were primarily concerned to learn about the biology of the budworm and the kinds and severity of damage it caused. Since 1950, they have developed sophisticated methods for surveying outbreaks, mapping their exact areas and assessing damage; also they have experimented with various chemicals in trying to control populations and thereby prevent further outbreaks.

The western spruce budworm has chiefly attacked the Douglas-fir, grand and subalpine firs, and Engelmann spruce; it has also attacked western larch, ponderosa pine, and western hemlock. Nearly all forests within the territories of the Northern and Intermountain Regions of the USDA Forest Service that contain these host species have been attacked sometime within the past 50 years. By partial defoliation of nearly all trees over large areas the budworm eliminates age classes of timber and thereby abruptly changes modes of forest management; it vastly increases fire hazard and eliminates recreational values.

In a typical outbreak, the budworm may consume part or all of the needles produced in the current season. If it consumes all of the needles produced during successive seasons, the tree may die within 3 to 5 years.

Since no natural agent capable of adequately controlling outbreaks of the budworm has appeared, forest entomologists have tried several chemicals as aerial sprays in attempts to control the pest and reduce its damage. These have included DDT, malathion, and several others. Their effectiveness, persistence, and side effects are varied. Despite availability of increasingly sophisticated devices for survey and development of several reasonably effective chemical controls more than 5 million acres of forests are still infested. The task of control is so great that thus far control programs have been concentrated only on areas where heavy damage has occurred or where extensive tree mortality is imminent. This indicates that the budworm problem will continue to plague western forests indefinitely.

OXFORD: 416.11; 453--145.718.28*

KEYWORDS: defoliation damage, tortricidae (-forest damage), western spruce budworm, outbreaks, host tree species, host tree impacts, biological control, chemical control.

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Douglas-fir forest devastated by the western spruce budworm,
Helena National Forest, Montana.

INTRODUCTION

The western spruce budworm,[1] a conifer-feeding species, is one of the most widely distributed and destructive forest insects in western North America. Its presence here as a native insect pest has been known since the late 1800's from specimens collected by entomologists from farflung localities and later identified by insect taxonomists. However, no one reported epidemic infestations of the budworm until 1909 in British Columbia and 1922 in Idaho. In the past 50 years, many outbreaks[2] of the western spruce budworm have been reported in Rocky Mountain forests in stands of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), true firs (*Abies* spp.), Engelmann spruce (*Picea engelmannii* Parry), and western larch (*Larix occidentalis* Nutt.) in the American northern Rocky Mountain area, which roughly encompasses the Northern and Intermountain Regions of the USDA Forest Service.[3] Of even greater significance is the fact that visible defoliation caused by western spruce budworm infestations has been reported by at least one Ranger District in these two Forest Service Regions every year since 1922.

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[1]*Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae) is a new species, established in 1967 (*47*) with the new common name, "western spruce budworm," which was adopted in 1970 (*7*). These names now apply to the insect formerly known in the Western United States as the spruce budworm, *C. fumiferana* (Clemens) and, prior to 1947, by the following generic and specific names: *Tortrix fumiferana* Clemens (1865), *T. nigrida* Robinson (1869), *Harmaloga fumiferana* (Clemens) (1913), *Archips fumiferana* (Clemens) (1929), and *Cacoecia fumiferana* (Clemens) (1943). Genetically and morphologically distinct from *C. occidentalis*, the spruce budworm, *C. fumiferana*, is a native insect pest of spruce and balsam fir forests in the Eastern United States and in Canada from the Maritime Provinces to the Yukon Territory. (In this paper, italicized numbers within parentheses refer to "References," numbers preceded by "U" refer to "Unpublished References.")

[2]Throughout this paper, *outbreak* designates a sudden large increase in population; *infestation* indicates a prolonged abnormally large population of the insect.

[3]Administrative Regions of the USDA Forest Service. The Northern Region (Region 1) includes 14 National Forests in northeastern Washington, northern Idaho, Montana, and northwestern South Dakota. The Intermountain Region (Region 4) encompasses 16 National Forests in southern Idaho, western Wyoming, Utah, a small portion of western Colorado, Nevada, and a small area in eastern California. These two administrative Regions are the geographic territory served by the Intermountain Forest and Range Experiment Station, which directs research programs on forest- and range-oriented problems.

Host tree defoliation and mortality throughout millions of acres of coniferous forests infested in these outbreaks have not been measured, but over the years they have been overwhelmingly visible. The effect of outbreaks upon the ecology, silvics, and management programs of the infested forests, likewise, has not been measured except by limited sampling in some areas; however, the effects are unpleasantly obvious to managers of these forest properties.

Research on the western spruce budworm in recent years has been concerned chiefly with its population dynamics, behavior, genetic characteristics, and chemical control. Few investigations have been directed specifically to its relationship with its host tree species or to the patterns of its outbreaks. Such studies must ultimately be made. Fortunately, much basic information useful for these studies exists in numerous reports that document details of the chronology, geographic distribution, and general severity of many of the budworm outbreaks in the two Forest Service Regions.

The general purpose here is to review this information (mostly unpublished) as a background for continuing biological and ecological studies of this important forest insect pest and as an appropriate reference for investigations into its epidemiology. Specifically, our intent here is to (1) consolidate, summarize, and present information about the location, host types, duration, effects, and measures for control applied in past outbreaks; (2) discuss factors that appear to relate to the location, duration, and probable effect of budworm outbreaks in the two Regions; and (3) identify problems for further study to more accurately assess the impact possibilities of outbreaks of the budworm in host forests managed for specific uses.

Hopefully, this presentation underscores the importance of the western spruce budworm problem in the northern Rocky Mountain region and will stimulate the development and application of management techniques to prevent or reduce intolerable resource losses from occasional or recurring epidemic populations of the insect.

Some interesting and important aspects and sidelights of past outbreaks are included herein for both their historical and their biological significance.

CHARACTERISTICS OF THE REPORTING AREA

Outbreaks of the western spruce budworm reported here occurred in National Forests, National Parks, or in extensive tracts of host type forests privately owned or managed by governmental agencies within the administrative boundaries of the Northern and Intermountain Regions of the USDA Forest Service. Boundaries of these two Regions are based chiefly on political subdivisions, but they show some minor ecologic and economic distinctions. Some tree species, for instance, are unique to one or the other Region. Climatic and physiographic differences produce varied silvicultural and mensurational characteristics that are bases for some differing management objectives.

Studies in biogeography and geomorphology provide some scientific identification of the distribution of the forest lands. Biogeography accounts for occurrence and distribution of floral and faunal communities; geomorphology accounts for the landforms.

Forests in the Northern and Intermountain Regions that are hosts to the western spruce budworm are mostly within the Northern Rocky Mountain and Central Rocky Mountain subregions of the Montana Coniferous Forest Biome described by Shelford (*84*), or the Northern Coniferous Forest Biome described by Odum (*77*). Exceptions are a few small, scattered, high-elevation forests of Douglas-fir, white fir (*Abies concolor* (Gord. and Glend.) Lindl.)), Engelmann spruce, and subalpine fir (*Abies lasiocarpa* (Hook.)(Nutt.)) that are isolated projections of this biome into an adjoining biome--Shadscale/Kangaroo Rat/Sagebrush (Cold Desert and Semidesert Communities)--in western Utah and Nevada (fig. 1). This biogeographic subdivision is the ecologist's way of recognizing major variations in the climatic climax vegetation that comprises the coniferous forests throughout the two Forest Service Regions.

Geomorphologists recognize basic differences in landforms within the Regions. In their classification, the two Regions are part of five contiguous geomorphologic, or physiographic, provinces characterized by uniform expressions of the topographic elements of altitude, relief, and type of landforms (*93*). The geography of the Northern and Intermountain Regions separates into these geomorphic provinces (fig. 2).

Figure 1.--Biogeographic (ecologic) biomes and subregions in the Northern and Intermountain Regions. (Adapted from Shelford 1963.)

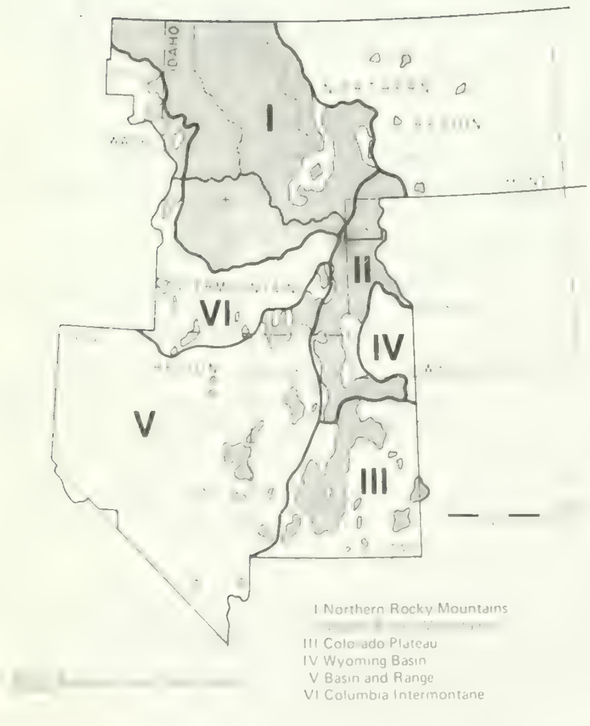

Figure 2.--Geomorphologic (landform) provinces in the Northern and Intermountain Regions. (Adapted from Thornbury 1965).

SOURCES OF INFORMATION ABOUT BUDWORM OUTBREAKS

The potential of the western spruce budworm for injuring and killing host trees began to be realized after several outbreaks of the insect in National Forests in northern Idaho and Montana during the 1920's. Growing concern over increasing depredations by this forest pest, heretofore not encountered in the northern Rocky Mountains, prompted National Forest administrators in both Regions to establish annual reports of budworm infestations beginning in 1925. That program has continued almost without interruption until the present and has provided one of the longest continuous records of epidemic infestations of a single forest insect pest to be found in the North American West.

Despite lack of complete scientific or political unity, the Northern and Intermountain Regions are treated here as a single reporting unit for budworm outbreaks. Responsibility for surveying the outbreaks and for evaluating, summarizing, and reporting the collected observations was divided between the Bureau of Entomology and Plant Quarantine[4] and the USDA Forest Service. Coordination of reports of outbreaks in both Regions was divided as shown below. Since 1961, reporting of insect conditions has been by the Division of State and Private Forestry in the Northern Region and by the Division of Timber Management in Intermountain Region. Despite this divided responsibility, there was interregional uniformity and continuity in developing techniques for detecting, evaluating, and documenting outbreaks that make joint consideration of budworm activities in the two Regions credible.

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[4]The Bureau of Entomology was later named Bureau of Entomology and Plant Quarantine. When it was abolished in 1953, its insect studies and control activities and many of its personnel were assigned to the USDA Forest Service.

Region	[illegible]	*Reporting source*
Northern	1925-1953	Annual surveys and reports of budworm infestations by National Forest district rangers; reports forwarded by Forest Supervisors to the Regional Office at Missoula, Mont., thence to the Bureau's forest insect laboratory at Coeur d'Alene for evaluating and summarizing.
	1948-1971	Annual surveys and reports of budworm infestations by entomologists of the Bureau's forest insect laboratory at Coeur d'Alene (1948-53); of the Intermountain Forest and Range Experiment Station at Coeur d'Alene (1954) and Missoula (1955-60); and of the Regional Office at Missoula (1961-71).
	1960-1969	Annual surveys and reports of budworm infestations in the Northern Region's Colville National Forest in northeastern Washington by entomologists of the Pacific Northwest Region (Region 6) at Portland, Oregon; by agreement between the two Regions.
Intermountain	1925-1951	Annual surveys and reports of budworm infestations by National Forest district rangers; reports forwarded by Forest Supervisors to the Regional Office at Ogden, Utah, for summarizing; thence to the Bureau's forest insect laboratories at Coeur d'Alene (1925-49) and Ogden (1950-51) for information.
	1950-1971	Annual surveys and reports of budworm infestations by entomologists of the Bureau's forest insect laboratory at Ogden (1950-53); of the Intermountain Forest and Range Experiment Station at Ogden (1954-60); and of the Regional Office at Ogden (1961-71).

A primary function of budworm surveys since 1925 has been to detect new outbreaks and to observe the progress of older active infestations. In most years, budworm surveys have examined outbreaks within National Forests and infestations of coniferous forests privately owned, or managed by Government agencies. Under this policy, entomologists from the Bureau of Entomology and Plant Quarantine or from the Forest Service have surveyed budworm infestations in Glacier and Yellowstone National Parks as part of their annual activity. Similarly, they have annually surveyed forests managed by the Bureau of Land Management, the Bureau of Indian Affairs, the Army Corps of Engineers, and forests owned by large lumber companies in Idaho and Montana.

Reports of the numerous extensive outbreaks of the budworm from 1922 through 1971 produced a cumulate record of destruction by a single forest insect pest that is unmatched. The record is unique for the mass and continuity of its collected information and for the great number of foresters and forestry technicians who collected this information during the first 30 years of this reporting. During the following two decades (roughly 1953-1971), an even greater amount of diverse information about outbreaks and continuing infestations was developed from the annual effort of fewer entomologists and foresters, who were using more sophisticated techniques and equipment for their surveys.

Annual surveys and reporting of budworm outbreaks were started in 1925 primarily because three men shrewdly recognized the destructive capabilities of the budworm in many forests on the northern Rocky Mountains. These men were James C. Evenden, Entomologist-in-Charge of the Bureau of Entomology's forest insect laboratory at

Coeur d'Alene, Idaho; and Elers Koch and R. H. Rutledge, District (now Regional) Foresters of the Northern and Intermountain Regions of the USDA Forest Service, headquartered at Missoula, Montana, and Ogden, Utah, respectively.

The dedicated performance of scores of National Forest District Rangers and their staffmen are responsible for success of the program of budworm surveys that continued for nearly 30 years. Their work in locating and determining the extent of outbreaks was arduous and time-consuming. Rugged terrain and lack of roads in most ranger districts denied them easy access to many outbreak areas. So these men viewed and mapped the expanse of many budworm-infested forests from vantage points on mountaintops and ridges frequently accessible only by laborious travel on foot or on horseback. Building roads into these remote areas later made it fairly easy to travel into infested forests and examine damage. These on-the-ground surveys were expensive in time and manpower, but results obtained by them compare favorably with results achieved by the refined methods used in insect surveys today.

Much present-day knowledge about budworm outbreaks and continuing infestations is available only because of the physical endurance and keen perception of those early rangers and technicians. Since so much of the information published here was available only from reports of specific outbreaks furnished by these men, we have identified each man by name wherever possible and have detailed their significant findings in tables 4, 5, and 6.

In 1948, the Bureau of Entomology and Plant Quarantine undertook responsibility for developing and conducting regionwide surveys of budworm infestations on all forested lands irrespective of ownerships. The first survey under this new sponsorship was made in Montana that year (*U107*). The reporting of budworm outbreaks by National Forest District Rangers was gradually phased out and was terminated in both Regions by 1953.

During this transitional period, entomologists of the Bureau explored the use of airplanes for surveying budworm outbreaks and for monitoring the performance of airplanes used for spraying chemical insecticides to control epidemic populations. Robert E. Denton and Tom T. Terrell in Missoula and Walter E. Cole in Boise, Idaho, developed the technology that established safe, effective use of airplanes for both spraying and monitoring (*U40, U215, U24*).

By 1955, entomologists throughout the northern Rockies were regularly using small well-powered airplanes to locate new outbreaks, to map their extent and that of continuing infestations, and to delineate outbreaks and existing infestations by relative intensities of host forest damage. The problems initially encountered with airplane performance, pilot skills, and observer proficiency had been largely overcome (*U48, U24*).

EARLIEST RECORDED OUTBREAKS

J. A. Fitzwater, Supervisor of the Kaniksu National Forest, headquartered at Newport, Washington, reported the first known outbreak of the western spruce budworm in this area in January 1922 from Kalispell Bay on Priest Lake in northern Idaho (*36, 37, 38, U60*). Fitzwater reported the dying of western hemlock, presumably from attack by an insect not yet identified.

In June 1922, Henry J. Rust, Entomological Ranger at the Forest Insect Laboratory in Coeur d'Alene, Idaho, collected feeding larvae from infested hemlock in the outbreak area. At the same time, he collected similar larvae from severely defoliated western larch, western redcedar (*Thuja plicata* Donn), grand fir (*Abies grandis* (Dougl.) Lindl.), western white pine (*Pinus monticola* Dougl.), and Engelmann spruce in the same general area. Specimen adults reared from these larvae at the Coeur d'Alene laboratory were identified by Carl Heinrich, a taxonomic specialist in the Bureau of Entomology, Washington, D.C., as *Harmologa fumiferana* Clemens. In response to the suggestion[5] that the Priest Lake outbreak might be the first to be recorded for this insect in the West, Heinrich wrote:

> It is somewhat doubtful how long the budworm has been working in the West, but inasmuch as it is an American insect, it is quite likely that it has been present there a long time. It is now known from British Columbia to the Southwest and most everywhere that hemlock and spruce occur.

Heinrich's reference to the geographic distribution of the budworm presumably was based upon specimens of the insect collected from locations throughout the Western United States and Canada rather than from reported outbreaks. In fact, outbreaks of the spruce budworm had been reported as early as 1907 on "spruce trees in Manitoba" and in 1909 in forests of Douglas-fir near Victoria and Duncan on Vancouver Island, British Columbia (*51*). There is some doubt whether the insect reported in the 1907 "spruce trees in Manitoba" was mistaken for the eastern form of the budworm, *Choristoneura fumiferana*, or whether this was indeed the western form, *C. occidentalis*.

Yellowstone National Park in Wyoming, Idaho, and Montana was the site of one of the earliest outbreaks of the western spruce budworm in stands of Rocky Mountain Douglas-fir in the Blacktail Deer Creek basin. Entomologists ascertained that the infestation, first reported in 1923, had persisted since about 1919 (*U19*).

During the years that followed the report of the initial budworm outbreak at Priest Lake, forestry personnel submitted numerous reports of additional budworm outbreaks from widely scattered localities within National Forests of the area and from Yellowstone National Park (table 1). Millions of acres of host forests felt the destructive impact of budworm outbreaks in subsequent years--extensive damage that earned the budworm its present reputation as a formidable forest pest.

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[5] By James C. Evenden, Entomologist-in-Charge, Coeur d'Alene Forest Insect Laboratory.

SALIENT FEATURES OF OUTBREAKS

Chronology

Annual reports of forest insect conditions prepared by National Forest ranger districts ably documented the sequence of budworm outbreaks in Montana and northern Idaho from 1925 to 1953. Ranger district reports of active infestations (table 2) revealed that the insect was most active in the Clearwater and Nezperce National Forests in Idaho and in the Beaverhead, Deerlodge, Flathead, Gallatin, Helena, Lewis and Clark, and Lolo National Forests in Montana. Despite having vast areas of possible host forests, the Colville National Forest in Washington reported no budworm outbreaks; and the remaining National Forests in Idaho and Montana harbored only a few widely scattered outbreaks.

The year-to-year prevalence of the budworm during this early period was particularly evident in the Nezperce National Forest in Idaho and in the Gallatin and Helena National Forests in Montana. The Townsend ranger district of the Helena National Forest has reported active infestations of the budworm within its borders every year since 1925, a record unequaled elsewhere in the two Regions.

During the early budworm infestations in the 1920's and early 1930's, outbreaks occurred almost annually in the Boise and the Payette (then Weiser) National Forests in west central Idaho. Outbreaks were reported less frequently from the Challis (then Lemhi) and Sawtooth National Forests in this same general area and from the Bridger and Teton National Forests in western Wyoming and the Targhee National Forest in eastern Idaho.

No significant budworm outbreaks were reported anywhere in the Intermountain Region from the early 1930's until about 1950.

The budworm's potential as a forest insect pest prompted both Regions to inaugurate systematic annual surveys of outbreaks in 1950 to accurately map their extent and to assess their impact on the infested host forests. Survey techniques and reporting standards were established, and entomologists were especially trained to use aerial surveillance.

On the ground, entomologists of both Regions observed and measured the nature and severity of defoliation (*U179*). Both in the field and in the laboratory they used specific biological techniques to measure the density of current budworm populations and to predict any changes in this density for the following year (*U43*, *U218*). Reports based on these surveys provide a detailed account of the location, extent, and relative severity of host forest defoliation or tree mortality caused by the budworm in the Northern Region since 1948 (*U107*) and in the Intermountain Region since 1950 (*U185*). The information in these reports, presented by States and National Forests or other forest management units, makes it possible to pinpoint the location of active budworm infestations each year.

In the Northern Region, for instance, entomologists' reports disclosed that 11 of 16 National Forests sustained budworm outbreaks in host stands for most of the years between 1948 and 1956 and between 1960 and 1971 (table 3). Similar frequency of outbreaks during these years was reported from Yellowstone National Park and a large tract of private timberland on Craig Mountain southeast of Lewiston, Idaho. The greatest number of outbreak years was reported from 7 of 10 National Forests in Montana, from the Clearwater and Nezperce National Forests in Idaho, and from Yellowstone National Park. Only the Coeur d'Alene National Forest in Idaho and the Kootenai National Forest in Montana were free of recorded budworm outbreaks during the 1948-1971 period.

Outbreaks were reported similarly in the Intermountain Region for 22 years beginning in 1950. Six of that Region's National Forests reported outbreaks almost annually (table 3), whereas surveys disclosed that outbreaks in other National Forests in the Region were infrequent.

The chronology of outbreaks of the western spruce budworm in National Forests and other public lands in this area can also be determined from the information in tables 4, 5, and 6 for the period 1922 to 1953, and in tables 7 and 8 for the period 1948 to 1971.

Information is scant on outbreaks that may have occurred prior to 1950 in extensive tracts of privately owned host type forests in Idaho and Montana. Since then, Forest Service annual surveys of budworm outbreaks have covered these tracts, and all publicly owned forest land outside of National Forests and National Parks.

Host Tree Species

The most frequently reported hosts of the western spruce budworm in the Northern and Intermountain Regions are these six species:

Rocky Mountain Douglas-fir
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco;

Grand fir
Abies grandis (Dougl.) Lindl.;

Engelmann spruce
Picea engelmannii Parry;

Subalpine fir
Abies lasiocarpa (Hook.) Nutt.;

Western larch
Larix occidentalis Nutt.; and

White fir
Abies concolor (Gord. & Glend.) Lindl.

General distributions of these species are shown in figure 3. Patterns of distribution for Douglas-fir, spruce, and subalpine fir are strikingly similar throughout their range. Spruce and subalpine fir often occupy the same high-elevation sites, but are separated from Douglas-fir stands by such physiographic features as topography, exposure, elevation, precipitation, or air temperature. Forests of grand fir, western larch, and white fir are more restricted in their distribution, but they fit within the broader distributions of the three species just mentioned.

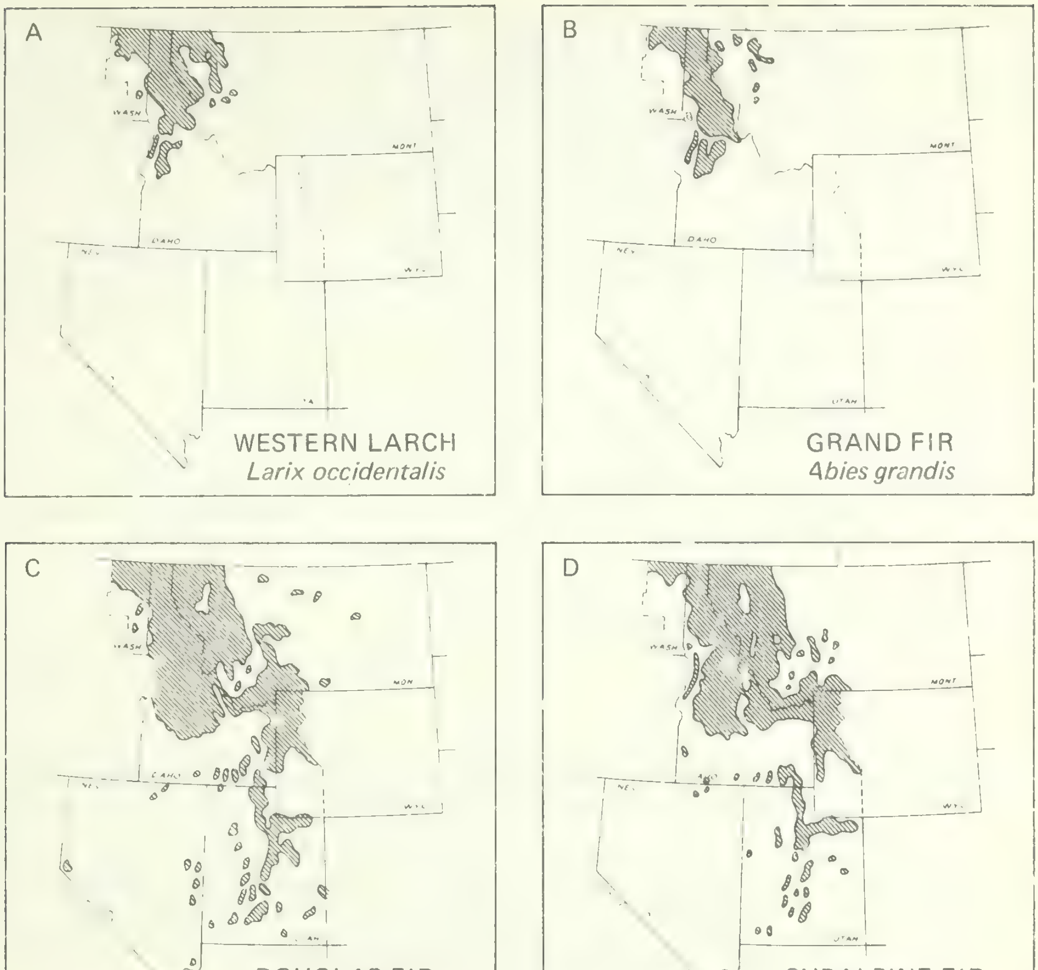

Figure 3.--Distribution of major host species for the western spruce budworm in the Northern and Intermountain Regions. (From Fowells 1965.)

Combinations of the six major budworm host species named above occur frequently in some localities: Douglas-fir and grand fir in northern Idaho; Douglas-fir and western larch in western Montana; and Engelmann spruce with subalpine fir at the higher elevations in both States. Only Douglas-fir grows extensively in pure stands, principally in central Idaho and in Montana mostly east of the Continental Divide.

Six additional coniferous species are occasional hosts of the budworm:

Ponderosa pine
Pinus ponderosa Laws.;

Lodgepole pine
Pinus contorta Dougl.;

Western white pine
Pinus monticola Dougl.;

Western hemlock
Tsuga heterophylla (Raf.) Sarg.;

Mountain hemlock
Tsuga mertensiana (Bong.) Carr.; and

Western redcedar
Thuja plicata Donn

Use of the foliage of these trees for food is survival behavior of budworm larvae when foliage from preferred trees is no longer available.

Reports in 1929 and 1930 attributed extensive defoliation of lodgepole pine forests in Yellowstone National Park to the budworm (*U14, U15*); recently that defoliation has been determined to have been caused by another budworm, *Choristoneura lambertiana* Freeman, a pest of several species of pine in the northern Rocky Mountain area.[6] Upon first examination, the two species appear quite similar.

Most outbreaks of the budworm have been reported from forests of Douglas-fir in Montana, Yellowstone National Park (Wyoming, Idaho, and Montana), south central and eastern Idaho, western Wyoming, Utah, and northeastern Nevada. Other host forest types, however, have supported some significant outbreaks of the insect: (1) mixed forests of Douglas-fir and grand fir in northern Idaho, where both tree species often serve simultaneously as hosts; (2) forests of pure Engelmann spruce in Glacier National Park, Montana; (3) mixed forests of Engelmann spruce and subalpine fir, where both species usually serve together as hosts; and (4) quite recently, in pure forests of young western larch in western Montana, which are mostly in plantations.

Defoliation of western larch by the budworm has been reported occasionally in the last 50 years in this area. The importance of larch as a host for the budworm was enhanced in the early 1960's when the insect was found damaging or destroying cones and seeds on older larch trees and severing the stems of terminal and lateral shoots of young western larch trees (*42, 83*) Since then, stem severing by feeding larvae has been found in western Montana wherever populations of the budworm are epidemic in stands of seedling, sapling, or pole-size western larch.

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[6]Personal correspondence from T. N. Freeman, Insect Taxonomist, Entomology Research Institute, Ottawa, Ontario, Canada, December 18, 1968.

Identity of major host species and frequency with which each species was infested were determined chiefly from the annual reports of budworm outbreaks prepared by National Forest District Rangers in the Northern Region from 1925 to 1953 (table 9). Douglas-fir was by far the most frequently reported host tree species; it was followed successively by grand fir, Engelmann spruce, subalpine fir, and western larch. White fir (*Abies concolor*) does not grow in the Northern Region.

Lodgepole pine was noted as a budworm host in several ranger district reports. From present knowledge, we cannot determine whether lodgepole pine was an accidental host of the budworm or a major host of the pine-infesting *Choristoneura lambertiana* in the same area. Most likely, it was the latter.

Western hemlock and western redcedar are not included in table 9 even though both species were hosts in the first budworm outbreak reported in northern Idaho in 1922. Host tree species mentioned in specific outbreaks described in the District Ranger reports from 1925 to 1953 are included in table 4. Host species in outbreaks in Glacier and Yellowstone National Parks and in the Intermountain Region between 1922 and 1964 are listed in tables 5 and 6, respectively.

We first observed defoliation of mountain hemlock by the budworm in the Clearwater National Forest in the summer of 1972.

Many forests containing host tree species acceptable to the budworm are known to be uninfested. Among them are those in northeastern Washington, in Idaho generally north of the St. Joe River, in Montana generally north and west of Flathead Lake, as well as some in Utah and Nevada.

Geographic Distribution

Many reports of budworm outbreaks submitted by District Rangers from 1925 through 1953 included maps of infested areas (fig. 4). Because many reports did not include such maps, cartographic representations of the outbreaks are not possible. However, we can picture the geographic distribution of budworm outbreaks in the Northern Region during these years by arranging the reporting National Forests and ranger districts in a schematic format, as in tables 10 and 11. In this arrangement, each ranger district receives equal value as an area of infestation regardless of the infested acreage it reported. These tables show that (1) budworm outbreaks covered significant areas in the present-day Clearwater and Nezperce National Forests from 1926 to 1933, (2) outbreaks persisted in one or two ranger districts in the Helena National Forest during the entire period from 1925 to 1953, and (3) short-lived outbreaks appeared in some ranger districts in a few National Forests widely scattered throughout the Region during this period.

In the Intermountain Region during this same period, similar but less frequent ground surveys by District Rangers disclosed outbreaks of the budworm primarily in the Boise and present-day Payette National Forests and only sporadic, brief outbreaks in other widely separated National Forests. This Region reported no significant outbreaks of the budworm from the early 1930's until 1950.

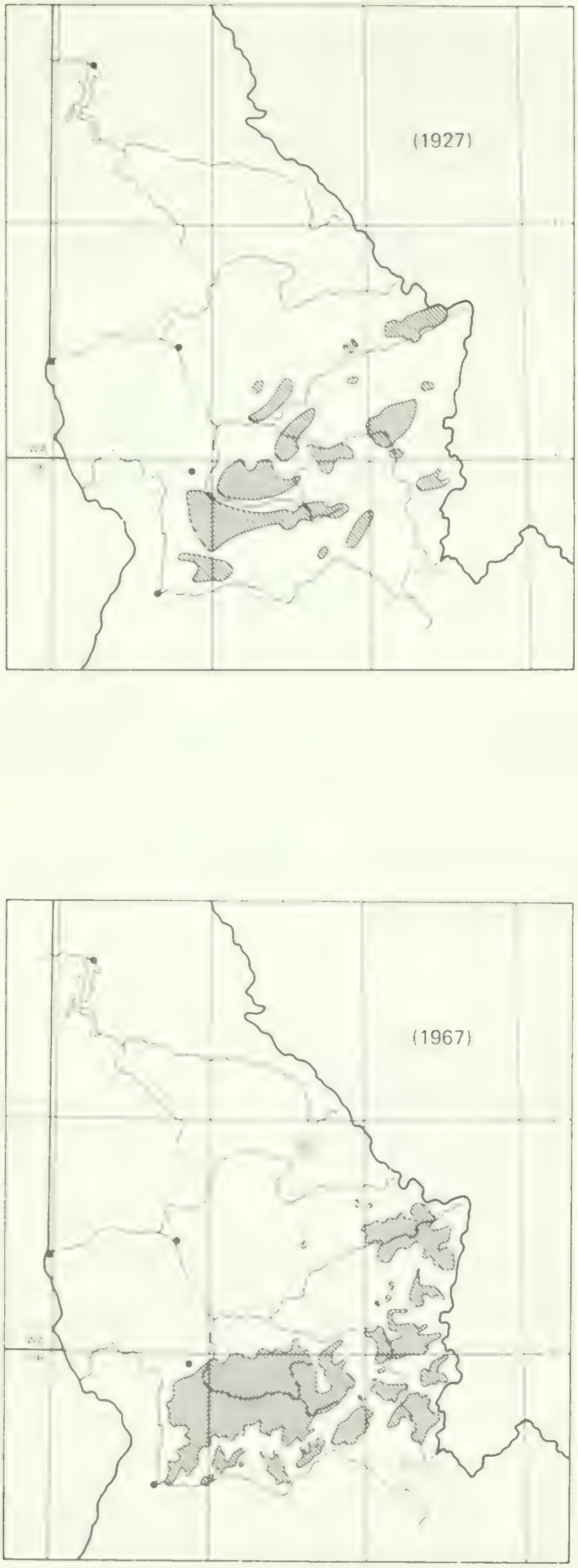
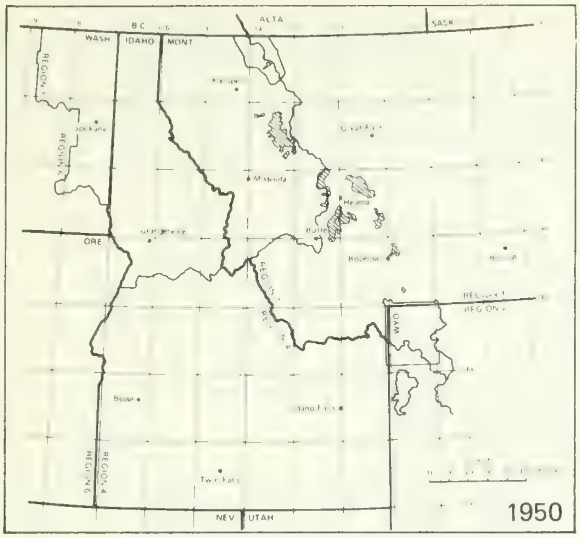
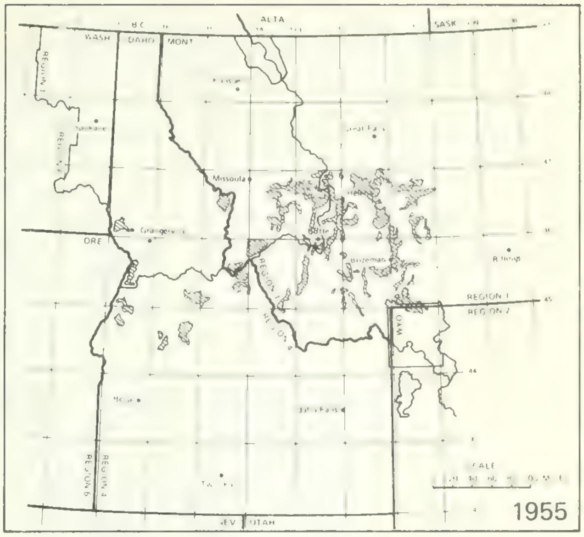
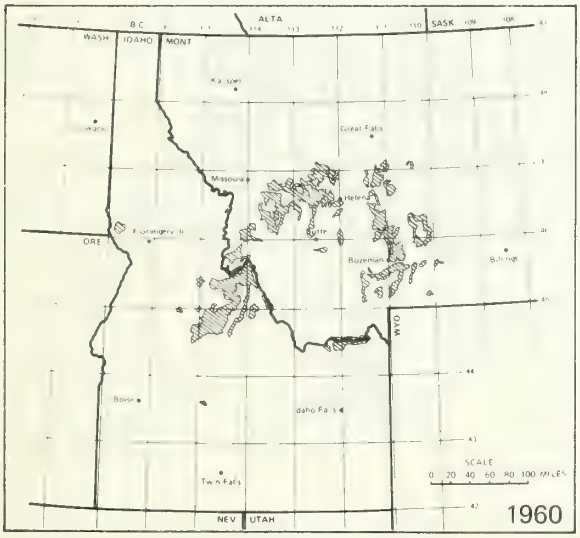
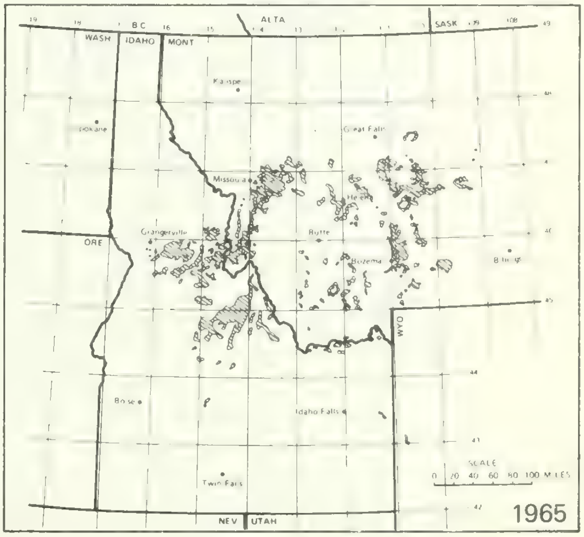


Figure 4.--Similarity in geographic distribution of outbreaks of the western spruce budworm in the Northern Region, 1927 and 1967.









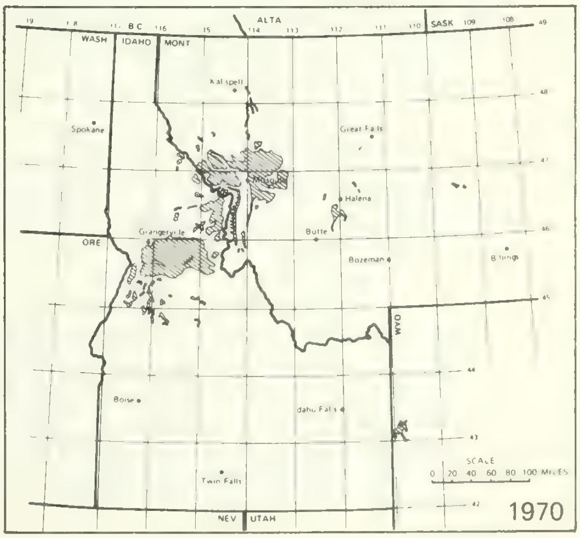


Figure 5.--Distribution patterns of aerially visible forest defoliation by the western spruce budworm in the Northern and Intermountain Regions at 5-year intervals, 1950-1970.

Brown (*13*) depicted the changing pattern of widespread budworm outbreaks in eastern Canada over a span of time with the aid of a cartographic series that plotted the position and shape of infestations annually or periodically from 1909 to 1966. A similar representation of outbreaks of the western spruce budworm in the Northern and Intermountain Regions (fig. 5) identifies several distinguishable patterns of distribution between 1948 and 1971:

1. Outbreaks predominantly in forests of pure Rocky Mountain Douglas-fir in Montana east of the Continental Divide, and west of the Divide in extensions of this host type, from 1948 to 1966 (Beaverhead, Custer, Deerlodge, Flathead (in part), Gallatin, Helena, and Lewis and Clark National Forests; in the Garnet Range east of Missoula, Mont., in lands administered by the Bureau of Land Management).

2. Outbreaks in western Montana in forests of mixed Rocky Mountain Douglas-fir, western larch, and ponderosa pine, from 1966 to 1971 (Bitterroot and Lolo National Forests).

3. Proliferation of outbreaks in northern Idaho in forests of mixed grand fir and Rocky Mountain Douglas-fir, both serving as hosts, from 1966 to 1971 (Bitterroot, Clearwater, and Nezperce National Forests).

4. Geographically stable outbreaks, but with fluctuating intensities from 1954 to 1971 in west central Idaho (Boise, Challis, Payette, Salmon, and Sawtooth National Forests) and in the eastern Idaho-western Wyoming area (Targhee, Bridger, and Teton National Forests).

These aerial survey-based representations show that budworm outbreaks in the Northern Region have undergone some massive displacement, while those in the Intermountain Region have remained in essentially the same geographic locations in recent years.

Area of Defoliated Forests

The area of defoliated host forests is one of several measurable data used to describe the damage from specific budworm outbreaks. Area is often used as the sole measure, probably because it is quite easily obtained and is the datum most frequently provided by aerial surveys of infested forests.

In northern Idaho and in Montana, reports of budworm outbreaks submitted between 1922 and 1953 often estimated the gross acreage of defoliated forests (tables 4 and 5). Some contained maps delineating the defoliated areas; these substantiated the estimates. However, these reports cannot be used to compute Regionwide estimates of the acreage of budworm-infested forests for each year of the reporting period.

Estimates of areas of defoliated forests and other descriptive data in the reports strongly indicate that at least 750,000 acres of Douglas-fir and grand fir forests were defoliated in 1930, the year when budworm outbreaks in northern Idaho between 1926 and 1933 apparently reached their maximum intensity. Most of this defoliated acreage was concentrated in the present-day Clearwater and Nezperce National Forests.

Estimates of acreage of budworm-defoliated forests have been computed yearly from aerial surveys of infested areas conducted since 1950 in the Northern Region and since 1954 in the Intermountain Region. From a low of 270,000 acres in 1948 (estimated from an intensive ground survey), single-year estimates of budworm-defoliated forests soared to nearly 4.9 million acres in 1958 and 1959 in the Northern Region and to 2.3 million acres in 1964 in the Intermountain Region (table 12). These single-year estimates do not reveal the cumulative acreage of host forests defoliated in each Region over the total reporting period.

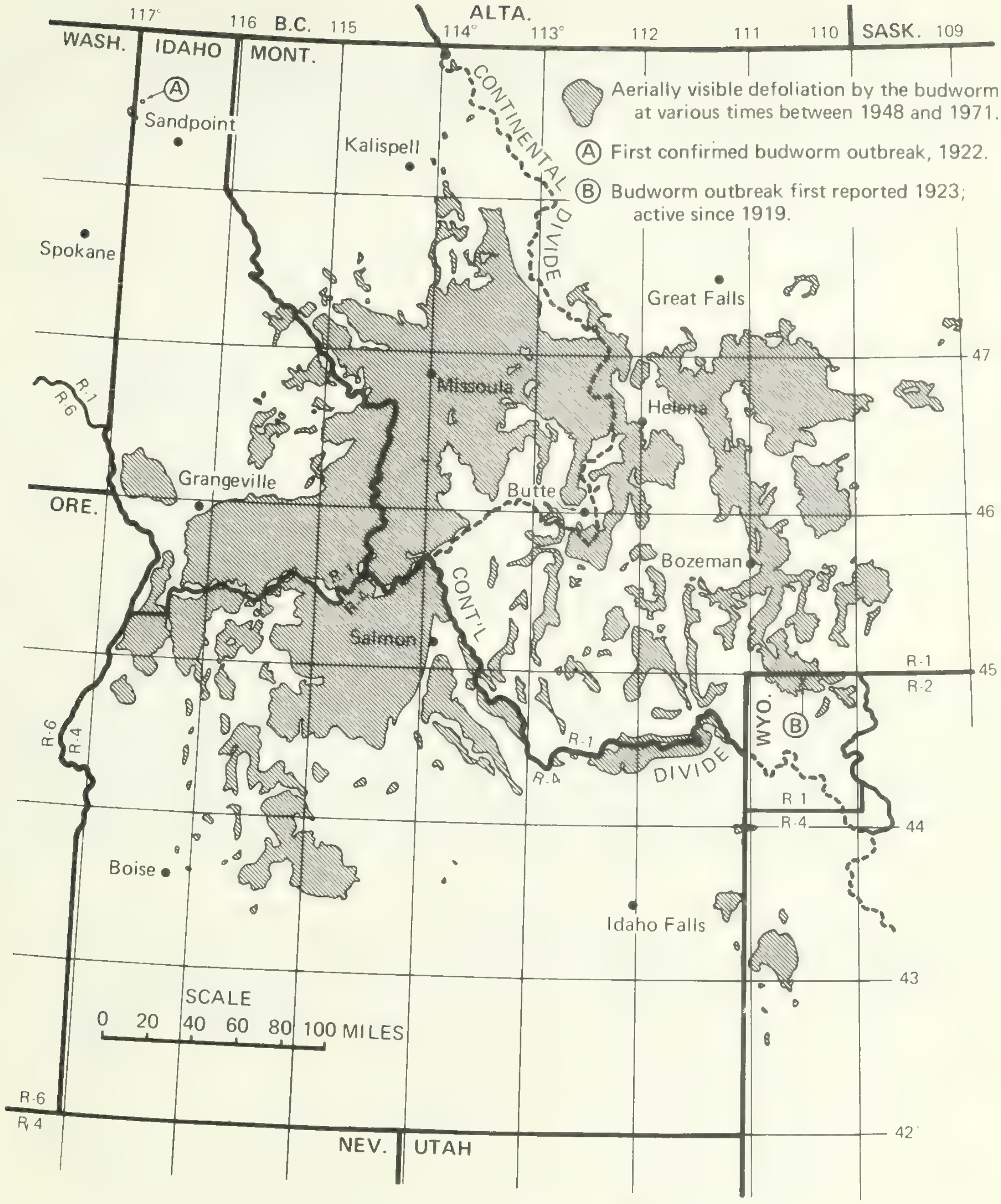


Figure 6.--Areas of major host types defoliated by the western spruce budworm in the Northern and Intermountain Regions at various times between 1948 and 1971. Few host forests within the general area of defoliation shown here escaped the damaging presence of the budworm at some time during the 24-year period. Interspersed among the defoliated forests are vast areas of forests immune to the budworm or nonforested lands. In contrast, extensive forests of several primary host species were not infested by the budworm during the period; notably those in the northwest corner of Montana, Idaho's panhandle, and in northeastern Washington. Neither was the budworm reported from most of the scattered host stands of Douglas-fir, Engelmann spruce, and subalpine and white fir in Nevada, Idaho south of the Snake River, western Wyoming, and Utah during the same period.

It is important to know how large an area in host forests had been invaded by the budworm to fully evaluate the effect of the insect on this resource. Consequently, the total acreage of host forests epidemically infested in each Region has been determined here by constructing a composite map of the outlines of defoliated forests (fig. 6). Computed gross acreages of all infested forests thus outlined were then reduced by one-third, a correction factor found necessary to eliminate reasonably consistent intermingled areas of nonhost forests or of nonforested lands too small to be feasibly mapped by aerial observers surveying outbreak areas (*U235*).

The technique described above has revealed that the net acreage of forests epidemically infested by the budworm for 1 or more years in this area is truly great, as shown in the following tabulation:

Region	*Reporting period, inclusive*	*State*	*Net infested acreage*
Northern	1948-71	Northern Idaho	1,912,350
		Montana	8,209,900
			10,122,250
Intermountain	1954-71	Southern Idaho	4,408,730
		Wyoming	180,430
			4,589,160

On the basis of the area of visible defoliation reported, five major cycles of budworm outbreak can be identified since 1926. The chronology and general location of the cycles are shown in table 13; figure 7 graphically portrays these infestations in terms of total acreage of host forests each one covered. Budworm outbreak cycle I, which persisted in northern Idaho between 1926 and 1933, was identified from annual reports of forest insect conditions by National Forest District Rangers. Absence of estimates of infested acreage from many reports precluded the plotting of this outbreak cycle in figure 7.

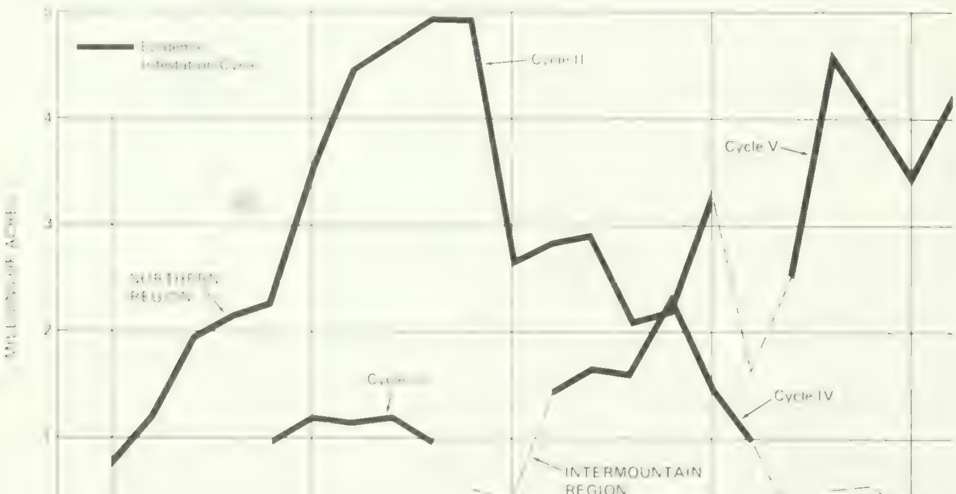


Figure 7.--Cycles of outbreaks of the western spruce budworm in the Northern and Intermountain Regions as determined from annual fluctuations in acreage of aerially visible defoliation. (Cycle I occurred in 1928-1933 (see table 13)).

Three cycles involved host forests in Idaho, but the single outbreak cycle in Montana (cycle II) continued longer and devastated more host forests. The fifth, and current, outbreak cycle extends from western Montana into northern Idaho and has already seriously defoliated many Douglas-fir and grand fir forests infested during cycle I. The ultimate damage to these forests from cycle V cannot be determined until it has run its course.

Duration

Visible budworm-caused defoliation and densities of budworm populations have not been measured for the express purpose of determining the longevity of any budworm infestations in this area. Some epidemic populations of the insect have been estimated in certain years to establish the need for chemical control of infestations the following year (*U218*, *U219*) or to predict the trend of other infestations (*U224*, *U238*). Such population estimates occasionally confirmed the beginning or ending of some outbreaks, but they lacked the needed year-to-year continuity to pinpoint both the beginning and ending dates that would establish duration. Many population estimates made as part of biological evaluations of budworm outbreaks, consequently, have not contributed much toward precise knowledge of duration of the insect's outbreak. For practical purposes, the period between the first and last appearances of visible defoliation is the most dependable criterion of budworm outbreak duration over large areas.

Nevertheless, the many reports of budworm activities in this mountain country contain clues to persistence of outbreaks. One is in the annual reporting of outbreaks in National Forest ranger districts and in Glacier and Yellowstone National Parks from 1922 to 1953, summarized in table 2. Recapitulation of the data in that table identifies 82 budworm outbreaks and indicates their duration as follows:

Duration of outbreak	*Idaho*		*Montana*		*Wyoming (Yellowstone National Park)*	
(Years)	*(Number)*	*(Percent)*	*(Number)*	*(Percent)*	*(Number)*	*(Percent)*
1-5	15	60	42	76	1	50
6-10	9	36	10	18	1	50
11-15	1	4	2	4		
16-20						
21-25						
26-30			1	2		
	25	100	55	100	2	100

This tabulation shows that most budworm outbreaks in northern Idaho and Montana between 1922 and 1953 lasted from 1 to 5 years.

Information in table 2 does not indicate that budworm infestations persist longer in the more humid environment of the grand fir--Douglas-fir of northern Idaho or in the drier environment of pure Douglas-fir forests east of the Continental Divide in Montana and in Yellowstone National Park. However, the longest consecutive reporting of budworm infestation was in this latter zone.

A further clue to the duration of budworm outbreaks is apparent from examination of the geographic distribution of aerially visible defoliation of host forests each year. Maps that outlined the Regionwide distribution of budworm-defoliated forests were prepared annually from 1948 to 1964 in the Northern Region and from 1954 to 1968 in the Intermountain Region. Superimposing the maps one at a time on a light-transmitting table enabled drawing of overlay tracings that outlined areas defoliated for 1 year and those continuously defoliated for 2 or more years.

The net acreage[7] of host forests defoliated during budworm outbreaks of varying durations was calculated by this method:

Duration of outbreak	*Northern Region*		*Intermountain Region*	
(Years)	*(Net acreage)*	*(Percent)*	*(Net acreage)*	*(Percent)*
1-5	4,838,030	69.6	4,037,190	88.2
6-10	1,490,390	21.5	359,850	7.9
11-15	598,700	8.6	178,610	3.9
16-20	20,380	0.3		

Dendrochronological techniques have successfully dated past outbreaks of the spruce budworm in the Eastern United States and Canada (*23, 5, 6*). Radial increment patterns are also being evaluated in the Northern and Intermountain Regions to date budworm outbreaks in relation to occurrence of various environmental influences or to measure the impact of outbreaks on the growth rates of budworm-defoliated trees.[8]

It is more difficult to use dendrochronological patterns to estimate duration of budworm outbreaks in the two western Regions than in the East because several other catastrophic defoliating arthropods, pathogens, and climatic phenomena are present in host and nonhost forests. Defoliation resulting from occasional and often persistent occurrence of these other agents can and does obscure defoliation caused by the budworm. This masking by other agents frequently prevents valid comparisons between radial growth patterns of infested and noninfested host trees and between those of infested host trees and nonhost tree species.

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[7]Net acreage is presumed to be approximately two-thirds of the gross acreage of defoliated forests aerially mapped during budworm surveys, to account for areas of nonhost forests and nonforested lands.

[8]Richard I. Washburn and William H. Klein, Principal Entomologist and Associate Entomologist, respectively, Intermountain Forest and Range Experiment Station, Moscow, Idaho, and Division of Timber Management, Intermountain Region, Ogden, Utah. Personal communications.

Defoliating agents on conifers include:

Agents	*Host tree species*	*Region of greatest occurrence*
Insects		
Black-headed budworm (*Acleris variana* Fernald)	DF,WH,ES,SF[1]	Northern
Lodgepole needle miner (*Recurvaria milleri* Busck)	LPP	Intermountain
Douglas-fir tussock moth (*Hemerocampa pseudotsugata* McDonnough)	DF,GF,ES	Nor./Int.
Spruce cone worm (*Dioryctria reniculella* (Grote))	DF	Nor./Int.
Larch casebearer (*Coleophora laricella* (Hübner))	WL	Northern
Larch sawfly (*Pristiphora erichsonii* (Hartig))	WL	Nor./Int.
Pine butterfly (*Neophasia menapia* (Felder & Felder)	PP	Nor./Int.
Sugar pine tortrix (*Choristoneura lambertiana* (Busck))	LPP,PP	Nor./Int.
Lodgepole sawfly (*Neodiprion burkei* Middleton)	LPP	Northern
Mites		
Spruce spider mite (*Oligonychus ununguis* (Jacobi))	DF	Nor./Int.
Diseases		
Dwarf mistletoe (*Arceuthobium* spp.)	DF,WL,PP,LPP	Nor./Int.
Needlecast fungi		
(*Rhabdocline pseudotsugae* Sydow)	DF	Nor./Int.
(*Elytroderma deformans* (Weir) Darker)	PP	Northern
(*Hypodermella laricis* Tubeuf)	WL	Nor./Int.
(*Lophodermella concolor* (Dearn.) Darker)	LPP	Northern
(*Meria laricis* Vuill.)	WL	Nor./Int.
Climatic		
"Red belt" winter drying	DF,PP,LPP	Nor./Int.
Extended drought	All	Nor./Int.

[1] Abbreviations of names of tree species here and elsewhere are: DF, Douglas-fir; GF, grand fir; SF, subalpine fir; ES, Engelmann spruce; PP, ponderosa pine; LPP, lodgepole pine; WL, western larch; WH, western hemlock.

Dendrochronological determination of duration of budworm outbreaks is further hampered in this area by (1) the absence, for tree ring comparisons, of nonhost tree species from many infested forests; (2) the lack of weather recording stations in the intimate forest environment which would indicate the microclimate and its effect on tree growth patterns in the abrupt mountain terrain that supports most budworm-susceptible forests; or (3) the possible arrest of declining radial increment in trees heavily defoliated by prolonged budworm infestation as epicormic branching develops, as spatial competition lessens following the budworm killing of nearby trees, or as infesting budworm populations were destroyed by large-scale aerial spraying of pesticides periodically in both Regions from 1952 through 1956.

Evidence indicates that most outbreaks of the western spruce budworm appear to persist naturally from 1 to 5 years. Outbreaks lasting to 10 or more years occur occasionally, and a few have continued even longer.

Factors Influencing Population Densities

Many surveys of budworm outbreaks since 1950 have included samples of the populations of hibernating instar II larvae, feeding instar IV or V larvae, pupae, adults, eggs, or egg masses (table 14). Measurements of these metamorphic populations (fig. 8) formed part of biological evaluations made to (1) determine the need for immediate action to reduce budworm populations to endemic levels in certain areas and (2) predict the trend of outbreaks in terms of the expected natural increase or decrease in the insect's numbers and the probable degree of subsequent defoliation (*8*, *9*, *U46*).

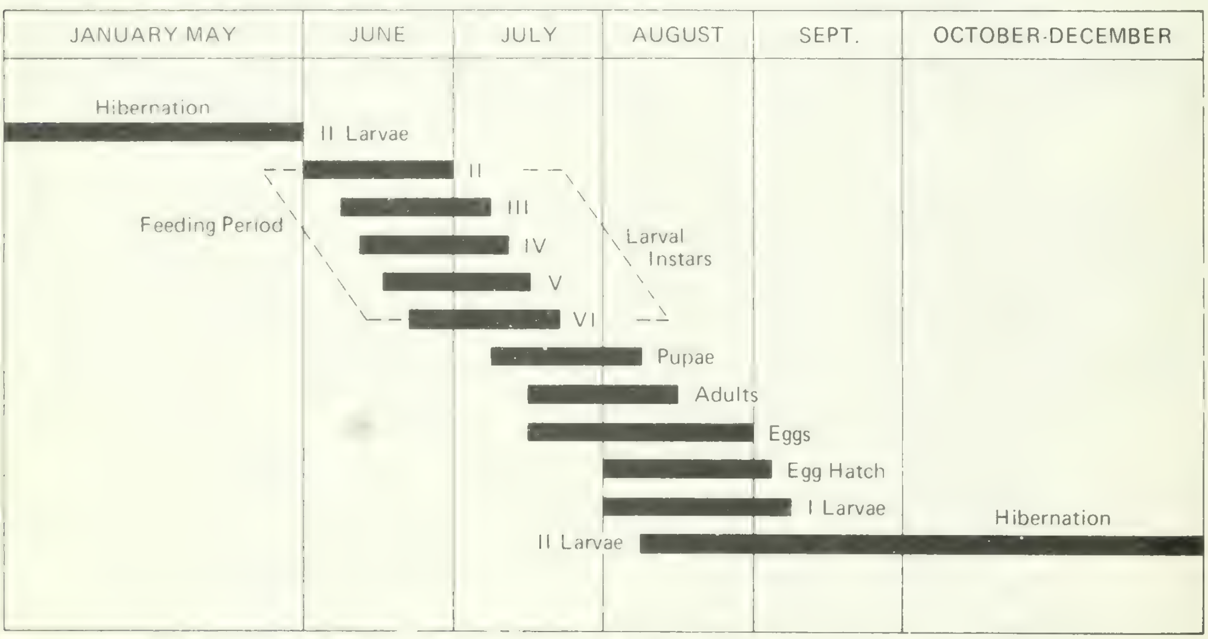


Figure 8.--Phenology of the western spruce budworm on Douglas-fir trees at 4,200 to 5,000 ft elevation in western Montana, 1963. (Data from Tom T. Terrell, associate entomologist, Northern Region, USDA Forest Service.)

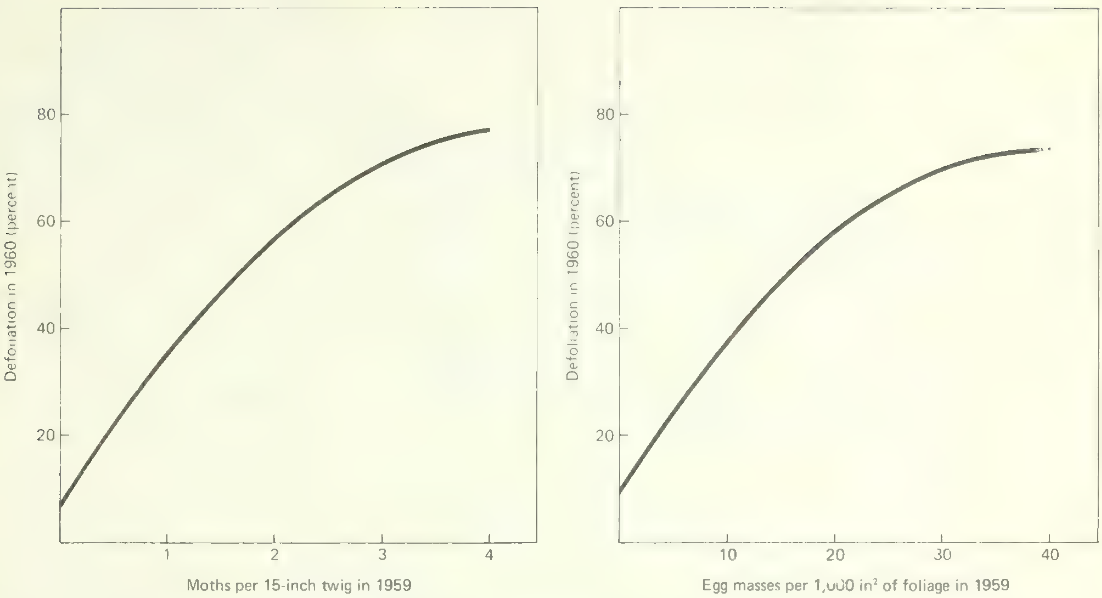
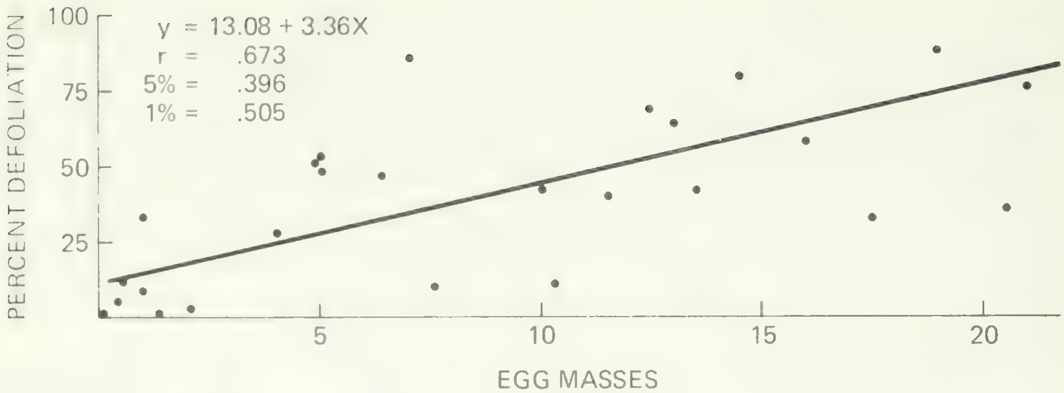


Figure 9.--Relationship between the average number of newly emerged moths and numbers of egg masses of western spruce budworm in 1959 and the average percentage of defoliation in 25 Douglas-fir stands in Montana in 1960. (From Terrell (U224))

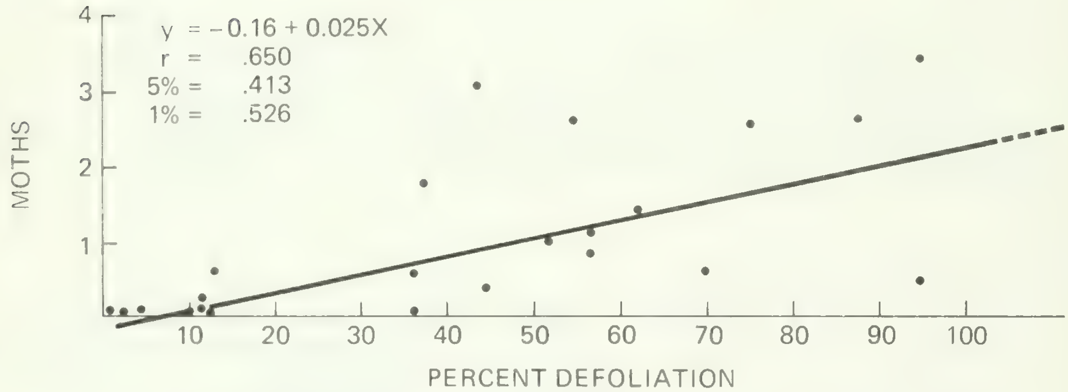
The first objective usually was easily achieved. Measurements taken during surveys either established the need for applied control action by confirming the presence of epidemic populations of the insect in specific localities, or they pointed to the futility of such action by revealing the absence of these populations in areas where they had been suspected. Measurements for this purpose are most effective if they are promptly applied to limited areas. These measurements were based on the premise that populations would change but little between the time they were measured and the beginning of control operations.

Under the same conditions, estimates of budworm populations adequately predicted trends of certain infestations and the probable amounts of defoliation to be expected during the budworm's next feeding period. Wherever the interval between population measurements and the following budworm feeding period was increased, the trends of infestations expressed by anticipated levels of population and defoliation were less accurate (table 15). During this lengthened interval there were more opportunities for changing biological and environmental factors to influence the size of subsequent measured populations.

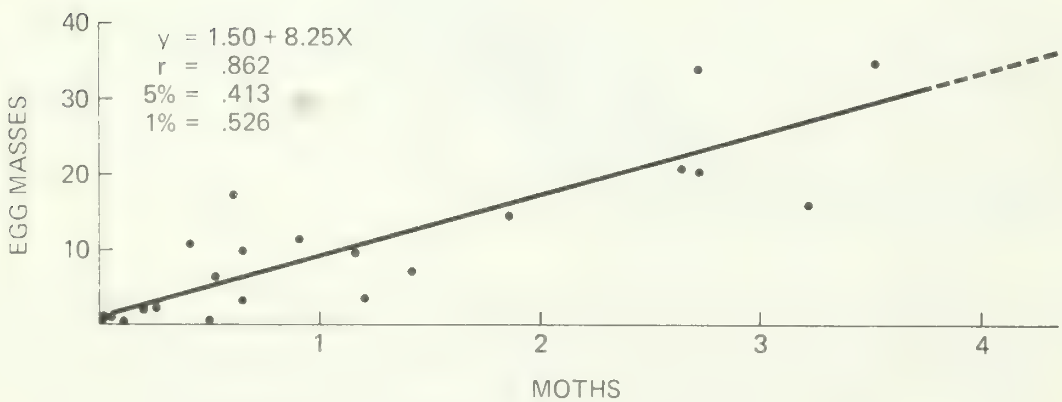
This interaction between biological and environmental factors usually regulates the density of a budworm population at any given time or place. It explains the wide difference in population densities over extensive areas in a given year (table 16). It also makes difficult the generalization of such particular budworm population correlations as those expressed in figures 9 and 10.



A. — Relationship of egg masses per 1,000 in ^{2} of foliage in 1958 to percent of defoliation in 1959



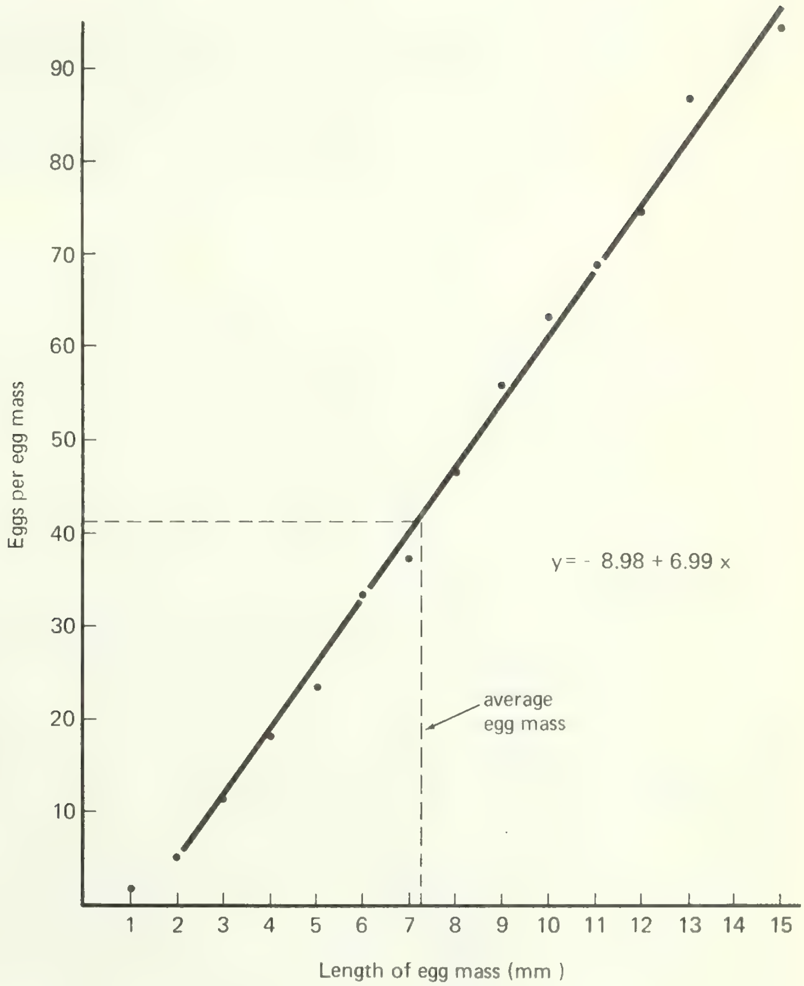
B. — Relationship of percent of defoliation to moths per 15-inch twig in 1959



C. — Relationship of moths per 15-inch twig to egg masses per 1,000 in ^{2} of foliage in 1959

Figure 10.--Relationships between numbers of egg masses, percentage of defoliation, and abundance of moths of the western spruce budworm in 25 Douglas-fir stands in Montana. (From Terrell and Fellin (U238))

Figure 11.--Relationship between length of egg masses of western spruce budworm deposited on Douglas-fir foliage in Montana in 1960 and the number of eggs per egg mass. (From Terrell (U224))



When sampling procedures are adequate, the abundance of current-season eggs appears to be more reliable than measurements of other metamorphic populations of the insect for predicting the trend of an infestation from year to year, and for forecasting the amount of defoliation expected the following year (*U224*). Recent biological evaluations of budworm outbreaks have used this measure of population almost exclusively. Egg masses can be readily collected and counted and the size of the masses can be quickly converted to numbers of eggs (fig. 11).

The destructive capability of each of the natural budworm control factors (described later in this paper) has been either measured or surmised from observations; but their epidemiologies, or occurrence patterns, are mostly unknown. Until this information is available, the appearance, probable severity, and subsidence of budworm outbreaks cannot be accurately forecast from weather or biological measurements made as part of outbreak evaluations.

EFFECTS OF OUTBREAKS ON HOST TREES

Defoliation resulting from consumption of part or all of the current season's needles by feeding instar II-VI larvae is the immediate and most obvious effect of infestation by epidemic populations of the western spruce budworm (fig. 12). It can be least damaging when it results from single-year outbreaks or from the first year of prolonged outbreaks. Physiological functions of the attacked trees can be maintained only by lessened photosynthetic activity of the remaining older needles. The physiology of infested trees may be more seriously impaired if the loss of current-season needles continues for 2 or more years. The foliage complement of trees may gradually diminish until crowns are completely defoliated.

Figure 12.--An example of 100-percent defoliation of current-season Douglas-fir foliage in the first year of an outbreak of western spruce budworm.

Whether defoliation resulting from budworm outbreaks is likely to be partial, and presumably recoverable, or complete, and doubtless irrecoverable, depends on (1) duration of the outbreak, (2) density of the budworm population, (3) relative susceptibility of individual host trees to larval feeding, and (4) stand composition.

The initial physiologic disturbance in infested trees is reduction in amounts of available carbohydrates. These food components required for tree life are chemical compounds synthesized in chlorophyll-containing needles by photosynthesis (*63*). When carbohydrate content is reduced, growth of vegetative and reproductive tissues and organs is reduced or aborted. If this debilitating action continues, the life and structure of affected trees deteriorate by the following process:

1. Stems produce less wood.

2. Fewer vegetative buds, flowers, and cones are produced.

3. Parts of the aerial and root structures die.

4. Abnormal budding develops that may deform both crowns and stems.

5. Root rots or bark beetles may subsequently infest weakened trees.

6. Whole trees may die.

Deterioration of completely defoliated host trees usually follows this recognizable syndrome that is often observed during budworm surveys:

1. The initial visible response of host trees is acceleration of adventitious vegetative budding; this produces numerous but stunted needles and in time is followed by suppression of budding.

2. The rate of annual radial and longitudinal increment declines.

3. Defoliated trees do not produce cones in years when cone production normally is high (*U265*, *U272*), even when the use of available carbohydrates for cone and seed development takes precedence over that for such vegetative parts as stem tips and cambium (*63*).

4. Top killing of tree crowns appears (fig. 13).

5. Rootlets die in the process of balancing the loss of photosynthetic surface caused by the defoliation (*63*).

6. Branches die as their foliage is destroyed.

7. Epicormic branches bearing juvenile needles (*16*) appear along the clear parts of the bole below the crowns, but sometimes they extend into the crown (fig. 14 and 15).

8. Tree may die from loss of all original foliage and the failure of epicormic-produced foliage to sustain physiologic functions.

Some species of host trees consistently suffer greater defoliation from budworm feeding than do other host species growing in the same forest community. In forests containing mixed stands of grand fir and Douglas-fir, white fir and Douglas-fir, or subalpine fir and Engelmann spruce, the first-named species often is the one more heavily defoliated. Douglas-fir in pure stands often is defoliated as heavily as *Abies* in mixed stands--sometimes more heavily. The frequency of budworm-caused mortality has been greatest in pure stands of Douglas-fir.

Figure 13.--Varied susceptibility of individual host trees to infestation by western spruce budworm. Exposure to several years of epidemic budworm populations left the Douglas-fir trees on the right almost completely defoliated. Neighboring Douglas-fir trees (left) exhibited only minimal tip killing similar to that often resulting from larval feeding during the first year of an outbreak.

Figure 14.--After losing most of its crown structure following several years of heavy defoliation by feeding budworm larvae, this Douglas-fir tree is surviving on aberrant foliage produced by epicormic branching and from restored normal foliage in the extreme top crown.

Figure 15.--Epicormic branching on mature Rocky Mountain Douglas-fir trees (center, left) stimulated by almost total defoliation and branch killing from infestation by successive populations of western spruce budworm. Survival of such trees is precarious until normal foliage complements are restored.

Seedlings, saplings, and pole-size trees growing under overstories of mature trees of the same budworm host species usually sustain greater defoliation and consequent mortality from the budworm long before their upper-canopy counterparts. This frequent happening is the basis for a popular belief that the budworm prefers young trees.

Young understory trees are defoliated, or die, sooner than older, larger infested trees in the forest for several reasons:

1. A larger proportion of the total foliage of young trees is current-season needles, which the feeding budworm larvae prefer; consequently, the complement of these needles is devoured or destroyed by feeding larvae very quickly. Young trees can be totally defoliated and killed in as short a period as the initial 2 years of an outbreak.

2. While fewer budworm eggs may be deposited in the understory trees, the population of feeding larvae may be extraordinarily dense because of developing primarily from larvae that have dropped from overstory trees either directly into the crowns of the understory trees or to the ground, from whence they can crawl into these crowns. Personal observations suggest that this transfer of larvae from overstory to understory trees may occur during any larval instar. On a unit of foliage basis, populations of budworm larvae feeding on understory trees at any given time may equal or exceed those on overstory trees that are supporting many times the amount of foliage.

3. Since small understory trees grow in shade and have less than a normal amount of foliage, their photosynthesis is limited and they cannot produce abundant carbohydrate reserve. Therefore, a reserve that is already largely suppressed can diminish or disappear quickly when photosynthesis is reduced further by defoliation.

Dendrochronographs from hundreds of increment cores and transverse bole sections collected from outbreak areas have revealed varied patterns of reduced radial bole increment from trees that have been partially defoliated or killed. Others are being studied to relate these declining growth rates to outbreak severity or to the occurrence and intensity of biotic or environmental factors that may have triggered them.[9]

Several considerations affect the amount and timing of reduced radial increment; they diminish the likelihood that defoliation results in any typical pattern of increment loss. These considerations also include the severity of defoliation, the number of seasons it continues, and the amount of reserve carbohydrates in the trees (*63*). Combinations of these factors, with other growth-inhibiting causes excluded, can create a myriad of patterns of growth loss. This theory appears to be substantiated by dendrochronological investigations of the western spruce budworm in British Columbia (*86*) and Oregon (*119*, *120*, *121*) and of the spruce budworm (*C. fumiferana*) in eastern North America (*5*, *6*, *23*).

After initial defoliation of current-season needles, the next visible indication that infested trees have become physiologically impaired is the dieback of the terminal and extreme uppermost lateral twigs. As in young trees, current-season needles comprise the major foliage complement of the upper crown extremities in older trees. Because most of them can be destroyed during the first year of an outbreak (fig. 13), experienced survey entomologists watch for this telltale sign of the budworm's abnormal abundance in a forest.

As the infestation continues into its second or third year, initial crown-tip killing may extend farther down the boles until a considerable portion of the upper crowns of infested trees is dead. This is the typical top killing that characterizes much of the visible host tree damage caused by budworm outbreaks.

Young coniferous trees overcome the loss of their upper bole terminals by replacing them with lateral branches that may develop into new vertical leaders. Mature trees are usually unable to replace top-killed portions of their boles. As defoliation voids the middle and lower branches of foliage, top killing may eventually encompass most of the crown portion of the boles. The dead stems, or "stag tops," may remain in place for years as an eyesore, as a likely site for decay, as an increasing cull factor, and as a hazard to woods workers.

Tree crowns approaching complete defoliation allow an increasing amount of light to reach heretofore shaded bole areas. This added light stimulates long-dormant epicormic buds along the boles; these buds may sprout if the outer bark is not too impenetrable ([illegible]). Epicormic branching that results from this sprouting produces a flush of juvenile foliage along the boles from points below to within the crown area (fig. 14 and 15). The chance of survival for trees in this stage of the budworm damage syndrome rests heavily on the permanence and photosynthetic capability of this epicormic foliage.

Epicormic-induced foliage that followed almost complete defoliation by the Douglas-fir tussock moth in northern Idaho in 1947 was unable to sustain mature grand fir trees for more than 1 year after the moth outbreak collapsed. In contrast, many Douglas-fir trees on xerophytic sites in central Montana have survived almost complete defoliation by the budworm, presumably because vital physiological functions of the trees were sustained by this type of foliage.

Sawlog-size Douglas-fir trees heavily defoliated by the budworm may become susceptible to lethal attacks by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins (fig. 16); this virtually assures the killing of trees that might survive the budworm.

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[9]Richard I. Washburn and William H. Klein. Personal communications.

Figure 16.--Stripped of most of its foliage by the western spruce budworm, this mature Douglas-fir tree became lethally infested by the Douglas-fir beetle, Dendroctonus pseudotsugae.

Outbreaks of the bark beetle in forests heavily damaged by the budworm have been reported occasionally from widely scattered localities since the 1930's. Several examples of such outbreaks are:

Administrative area	*Ranger District*	*Year*	*Reference*
Yellowstone N.P.	North	1924	(*U62*)
Yellowstone N.P.	North	1925	(*U19*)
Helena N.F.	Canyon Ferry	1949	(*U266*)
Helena N.F.	Townsend	1949	(*U266*)
Bitterroot N.F.	West Fork	1951	(*U257*)
Flathead N.F.	Big Prairie	1951	(*U114*)
Flathead N.F.	Spotted Bear	1951	(*U114*)
Gallatin N.F.	Bozeman	1958	(*U220*)
Gallatin N.F.	Bozeman	1966	(personal observation)

The death of trees, the final result of budworm infestation, has been abundant in some outbreak areas. Death of seedling, sapling, and pole-size host trees can usually be attributed to budworm-caused defoliation. Mature host trees may also succumb to this defoliation, but many survive; some may eventually die from subsequent attacks by bark beetles or other secondary insects.

EFFECTS OF OUTBREAKS ON HOST FORESTS

Reports of outbreaks of western spruce budworm during the past 50 years documented varied kinds and amounts of damage to the host tree element of involved forest ecosystems. Host forests occasionally survived outbreaks intact and comparatively unscathed. Others had residues of badly damaged trees, of dead trees, or both (fig. 17). Damage reported in most infested forests was estimated to have been somewhere between these extremes.

Figure 17.--This scene from Helena National Forest shows most of the common types of host tree damage caused by the western spruce budworm. Damage types represented: dead overstory tree (left), light tip killing (dominant tree, center), top killing (left of center), advanced defoliation (right of center), and extensive killing of understory trees (behind foreground trees).

We have reached this conclusion after studying subjective evaluations of the relative amounts of different types of tree damage or of dead trees made by many persons who investigated or reported the outbreaks. Their assessment of damage accrued during outbreaks, based on what was obvious and visible, was a valuable contribution to our knowledge of budworm epidemiology. We have left to forestry specialists the task of describing the longer term effects of the damage on the multiple resources of the infested forests.

Silviculturists have benefited from many cause-and-effect studies of biotic and climatic phenomena that influence tree growth and forest productivity. While few of these studies directly involved the budworm, results from some of them indicated that effects of certain phenomena were similar to those produced by the budworm. The effect of defoliation, for instance, is nearly always the same regardless of its cause. Because of this, silviculturists have long been able to foresee the nature, and often the magnitude, of temporary or more lasting effects of budworm outbreaks on the timber in host forests.

In the last two decades, specialists in the plant and animal sciences have adapted a growing amount of research-based information, or have directed more of their own research effort, to the forest environment. Statements about the effect of budworm outbreaks on all uses of host forests are beginning to appear frequently. Still, information exclusively on the effect of budworm outbreaks on the major uses and values of these forests is practically nonexistent.

By drawing on existing knowledge and on the considered judgment of specialists in forest use, we have compiled examples (table 17) of short- and long-term effects of budworm outbreaks on commonly recognized forest uses in the northern Rocky Mountain area.

The degree to which effects of budworm infestation listed in table 17 might appear in specific forests depends chiefly upon the intensity of feeding by one or more generations of budworm larvae. It depends also upon the combining of existing site and stand conditions with the appearance of certain biotic and climatic events:

1. The exposure, elevation, and general landform of the sites.

2. The physical, chemical, and water-holding properties of soils.

3. The species composition, density, and age class of trees in the stands.

4. The nature and abundance of ground vegetation.

5. The effect of other insect infestations or pathogenic infections to host and nonhost trees in the stands.

6. The effects of catastrophic fires or of weather preceding, during, or closely following the budworm outbreaks.

Over the years, many statements of the impact of budworm outbreaks on host forests have appeared. Some were made in reports of outbreaks to provide foresters and other land managers with some indication of the seriousness of the pest. Others were made to show need for costly budworm control programs. These early statements were based on conjecture, for it was not until the late 1950's that foresters attempted to ascertain specific impacts of some outbreaks.

A pioneering survey to determine the impact of budworm outbreaks was made during 1964 and 1965 in the Salmon and Challis National Forests by the Division of Timber Management, Intermountain Region, USDA Forest Service (*U195*). Established timber survey plots were used for measuring host tree radial increment, crown form damage, cone

production, regeneration, and outright mortality from outbreaks then in progress. The total damage of the outbreaks to commercial timber was a measurable objective, but the survey also attempted to evaluate subjectively the probable effect of tree damage on the functioning of watersheds, wildlife habitats, fisheries, and recreational areas.

Approximately 3,100 host trees at 66 sampling locations were closely examined. Most of them were within currently infested forests. Following are some types of damage measured in the survey, and potential effect on different forest resource values:

Commercial timber stands

1. Trees killed by the budworm were all less than 9 inches d.b.h. and averaged 19 per acre.

2. One-third of all trees tallied had some kind of crown form damage: dead tops, 16 percent; extreme top defoliation, 4 percent; or dead branches, 15 percent.

3. Marketable Christmas trees averaged 50 per acre; 68 percent of them had been rendered unfit for sale because of defoliation--an estimated loss of $34 per acre.

4. Despite a fair Douglas-fir cone crop in 1965, no cones were produced on trees more than 50 percent defoliated.

5. No Douglas-fir reproduction 6 inches or less in height was found at 30 sampling locations where site conditions were favorable but where defoliation of overstory trees had continued for 2 or more years; some reproduction was recorded at 28 other favorable sites, where defoliation was light.

Watersheds

Measured tree damage indicated no apparent effect on water production or patterns of runoff.

Fire hazard

Faster drying of fuels under defoliated tree canopies, probable increase in number and severity of fires from lightning-struck snags, and accumulated flash-type fuels (dead needles, twigs, and branches) were regarded as hazardous at some sampling locations but not at others.

Forage production

Abundance of forage plants was increased at 5 of 63 sampling locations where this factor was measured; trees at each of the 5 locations had been infested by the budworm for at least 5 successive years.

Wildlife

Severe tree defoliation at 2 of 63 sampling locations resulted in undesirable loss of cover for shading or concealment of animals. At 7 locations, desirable thinning of tree thickets enabled passage of animals and establishment of forage or browse plants.

Recreation areas

Recreation values were judged to have been reduced by budworm damage at 11 sampling locations. Factors assessed included loss of tree cover in picnic and campground areas and undesirable esthetic ratings for heavily defoliated forests within view of much-used sites and thoroughfares.

Studies in 1964-1968 of the budworm's larval feeding behavior revealed new forms of the budworm's impact on some host forests. For instance, a study in northwestern Montana disclosed widespread severing of the stems of new terminal and lateral shoots on young western larch trees (*42, 44, 83*). The feeding of several consecutive generations of budworm larvae in several naturally reproduced stands of seedling and sapling larch trees drastically increased the incidence of stem crook and multiple leaders among individual trees. The regenerative capability of the infested stands clearly had been jeopardized by the resultant reduction in juvenile height growth and increase in undesirable crown forms in a large proportion of the trees. Ironically, cone damage was heaviest in larch stands that suffered almost no defoliation. Data from the study were insufficient to determine how much of the larval stage was spent in the larch cones, or to what extent this form of damage prevails in budworm-infested forests of western larch (*45*).

A similar study revealed that the budworm had fed upon and destroyed more cones and seeds of Douglas-fir than any of 15 other cone and seed insects collected and reared from 13 sampling areas in western Montana and Yellowstone National Park during 1967, 1968, and 1969. Budworms were in cones from every area in each of the study years. Where defoliation was aerially visible, from 56 to 68 percent of all cones examined had been damaged by budworm feeding. In areas where budworm defoliation was not aerially detectable, cones damaged by this insect averaged from 22 to 25 percent of the total number sampled (*29, U53, U54, U55*).

In 1965 Fauss and Pierce (*40*) studied the relationship between site quality, crown closure, and the percentage of Douglas-fir and the amount of defoliation of this species from a 5-year-old infestation of the budworm in the Blackfoot River drainage of western Montana. They concluded that:

1. Defoliation was significantly less on moist bottomland sites than on drier hillsides.

2. Open stands were defoliated considerably less than stands having dense canopies.

3. Stands containing a low percentage of Douglas-fir were defoliated less than stands having a high percentage of Douglas-fir.

4. Buildup of budworm populations might be prevented silviculturally by reducing Douglas-fir stocking to low levels or by changing the stand composition to favor nonhost tree species; both these practices presumably are not needed on good quality sites and are economically unfeasible on poorer sites.

A survey conducted jointly by the Forest Insect and Disease Branch, Northern Region, USDA Forest Service, Missoula, Mont., and the Clearwater National Forest, Orofino, Idaho, in 1971 on 500 acres of the Yoosa Creek drainage of the Clearwater National Forest was designed to determine how much timber had been infested, how much top killing had occurred, and how much tree growth might have been lost from a budworm outbreak that began in 1966. The following volumes of budworm-infested timber were reported from the study area (*U98*):

Species	*Total volume/acre (Fbm)*	*Infested volume/acre (Fbm)*	*Percent*
Grand fir	9,403	9,317	99.1
Engelmann spruce	2,252	2,181	96.8
Douglas-fir	1,255	1,239	98.7
Subalpine fir	772	772	100.0
Western redcedar	405	0	0
Western larch	213	0	0
Western white pine	211	0	0

Top-killed grand fir trees were 4 percent of all trees of this species tallied, but were only 1 percent of the total volume; this indicated that the smaller grand fir trees were more readily top killed.

Radial increment for the 5-year infestation period averaged 22 percent less than for the previous 5 years in 12 trees representing the four major host species.

Two other surveys of the impact of budworm outbreaks were begun in 1971. Preliminary data were collected throughout the Intermountain Region to measure growth loss of host trees, crown form damage, and mortality, as well as other resource values that may have been affected by host tree damage. The study's aim was to determine how much resource damage can be tolerated by the several forest uses before expenditures for applied control are justified (*80*).

Pest control entomologists and timber management specialists in the Northern Region are measuring the impact of an outbreak of western spruce budworm that began in 1964 in the Nezperce National Forest. They are inventorying top-killed and budworm-killed trees from aerial photographs and from ground plots to ascertain the extent of permanent damage to the infested stands. From this inventory they can estimate resource losses on a compartment basis using multistage probability sampling. Stage I, a sketch map from an aerial survey, showed 138,000 acres of aerially visible top killing and tree mortality on the forest resulting from the current budworm infestation.[10]

Study of the impact of the western spruce budworm on host forests has priority in a proposed comprehensive research and development program that might be conducted jointly by the Forest Service, cooperating State agencies, and universities. Through systems analysis and computer experimentation, the program is designed to provide basic knowledge and understanding needed to develop an integrated system of techniques for managing population densities of the budworm.[11] Measurements of budworm populations will be correlated with host conditions to predict the intensity and extent of host damage and its relation to the forest resource.

By this coordinated approach, participating scientists and forest managers will try to assess the following impacts from budworm outbreaks:

1. Effects of budworm populations on growth and mortality of individual host tree species.

2. Frequency, duration, distribution, and severity of budworm outbreaks in the West since 1920, including geographic, historic, and climatic relationships.

3. Susceptibility and vulnerability of host trees and stands in various ecological environments and under varied management regimes.

4. Effect of budworm feeding on production of cones and seeds.

5. Susceptibility of host trees to other destructive agents after defoliation by the budworm.

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[10] Jerald E. Dewey, Entomologist, USDA Forest Service, Northern Region, Missoula, Mont. Personal communication.

[11] Boyd E. Wickman, Research Project Leader and Program Coordinator, USDA Forest Service, Forestry Sciences Laboratory, Corvallis, Oreg. Personal communication, Nov. 1972.

Figure 18.--This stand of Douglas-fir saplings and small poles in Deerlodge National Forest has undergone several years of heavy defoliation by the spruce budworm. Many trees have died; residual trees have sustained serious form damage.

Except in the matter of infested acreage already discussed, we cannot now quantify the massive damage tht the budworm has caused during 50 years of widespread outbreaks in the Rocky Mountain area. To those who investigated, surveyed, or reported the many outbreaks, the record of damage has been unmistakably visible and impressive:

1. The light, moderate, or heavy defoliation of millions of seedling, sapling, pole- or sawlog-size trees which, silviculturists know, represents enormous volumes of wood that were never produced.

2. The top killing and other crown or stem deformation that developed in millions of these trees as a secondary effect of defoliation; damage that contributed to staggering amounts of potential degrade and cull in poles and sawn products.

3. The killing of entire understory forests over broad areas and the general depletion of growing stock on many thousands of acres resulting from complete defoliation and consequent killing of millions of seedling, sapling, and pole-size trees (fig. 18).

4. The decimation of harvestable sawlog tree overstory stands on thousands of acres of host forests with resulting economic and esthetic losses (fig. 19); losses that added immensely to the costs of planning and managing forced salvage of dying and dead timber (fig. 20), increased fire protection, and the cleanup of recreational areas (fig. 21), roads, and trails.

Figure 19.--Defoliation from successive epidemic populations of western spruce budworm between 1948 and 1953 caused this catastrophic tree killing on a 500-acre south-facing Douglas-fir stand in White's Gulch, Helena National Forest.

Figure 20.--Frail remnants of a fully stocked Douglas-fir pole stand. Almost completely defoliated by an outbreak of western spruce budworm, these trees survived only because of extensive epicormic branching. Most trees killed during this infestation were cut and salvaged. Brackett Creek Drainage, Gallatin National Forest.

Figure 21.--Extensive tree killing and deformity of surviving trees following infestation by western spruce budworm in a recreation area in Gallatin National Forest between 1945 and 1950.

5. The further killing of heavily defoliated pole and sawlog trees by infestations of bark beetles--particularly by the Douglas-fir beetle in Douglas-fir trees--in the years immediately following the termination of some outbreaks.

6. The expenditure of nearly $8 million in operating costs for aerially spraying 6.3 million acres of host forests to control the more virulent budworm outbreaks; usually accompanied by equal or greater matching costs in contributed planning, supervision, or the conducting of concomitant ecological impact studies.

7. The indeterminable amount of time and expense in revising management priorities and planning in forests drastically altered by accumulated damage to host trees; planning that must acknowledge the likelihood of further damage from the budworm until such time as developing technologies for regulating budworm populations become feasible.

NATURAL CONTROL AGENTS

Abundant experimental evidence has established that population densities of most insects are rigidly controlled by complex interactions of certain measurable biotic and environmental factors (*49*). Populations of the budworm undoubtedly respond similarly to the changing complex of these factors. Densities of budworm populations fluctuate from year to year and from place to place in response to (1) changes in weather phenomena, (2) abundance of insect and other animal parasites and predators, (3) levels of insect pathogens, (4) sex ratios of the budworm, (5) fecundity rates of adult female budworms, (6) viability of budworm eggs, and (7) the quantity and quality of available food.

While the effect of some of these factors on density of budworm population is fairly well understood (*76*), less is known about the net effect of combinations of factors that may increase or decrease the numbers of budworms. Least known are the effects of these composite natural control agents in regulating budworm populations and the consequent severity of outbreaks of the insect. Except in a few isolated outbreaks where dramatic changes in the size of budworm populations occurred, or did not occur when they were anticipated, the precise influence of individual or collective causative factors has not been determined as part of biological evaluations.

Weather records, for instance, have usually been examined closely only when some meteorological abnormality was suspected of causing a readily observed change in the abundance of the budworm in an area, as in the following events:

1. Lightning-caused conflagrations in the Clearwater and Nezperce National Forests in the 1930's that destroyed or damaged extensive host forests and their infesting budworm populations, and which denied food over wide areas to succeeding populations that might have survived in the burned areas, or migrated thereto (*U253*).

2. The suspected killing of hibernating instar II budworm by unusually cold temperatures during the winters of 1923-24 and 1924-25 in the Gallatin National Forest ([illegible]), in contrast to the demonstrated survival of similar larvae in budworm-infested forests of Douglas-fir in the Blackfoot River drainage in western Montana, where temperatures during November 1959 reached lows of -45°F (-42.5°C) and -53°F (-47°C) (*U222*).

3. Unseasonably low air temperatures (18°F to 22°F (-12°C to -14.5°C)) in September 1965 in the Salmon National Forest which reduced egg hatching and presumably killed instar I and II budworm in high elevation host forests (*59*).

4. An unseasonably warm May followed by subfreezing air temperatures in the Salmon National Forest both early and late in June 1966, which killed a high percentage of the 1966 Douglas-fir foliage growth and the infesting instar III and IV budworm in it (*59*). This freeze undoubtedly had an indirect effect by destroying food that would have fed many surviving larvae. The mortality of budworms caused by this and the preceding autumn freezing weather justified cancellation of an aerial spraying program planned for July 1966 to control infestations in 120,000 acres of Douglas-fir forests.

5. Unseasonal air temperatures, as low as 21°F (-6°C), were recorded in the Clearwater and Blackfoot River drainages in western Montana in mid-June 1969, a period when budworm larvae were feeding on new foliage of host trees. Data from several ecological studies of budworm in progress in the areas provided evidence that populations were reduced by more than 90 percent on infested Douglas-fir, western larch, and ponderosa pine trees, and that budworm damage to young larch trees was reduced 54 to 71 percent from the previous year (*43*).

6. High surface winds associated with thunderstorm activity over the Helena National Forest on the afternoon of August 2, 1951, are believed to have concentrated flying budworm moths in infested Douglas-fir forests south and west of the city of Helena and to have positioned them to enable a strong phototropic response to carry them in a mass invasion of the urban center of the city on the windless evening of August 3.[12] [13] The junior author personally determined that a significant percentage of the moths in that spectacular flight were gravid females with partial or entire egg complements. In effect, the flight translocated a massive population of egg-bearing adult budworms from infested host forests to quick death in a sterile urban environment.

7. Other high velocity surface winds, common in the Rocky Mountains from high-low pressure gradients or from lee side turbulence caused by general westerly winds cresting sharp summits and low passes of north-south mountain ranges, frequent during the flight period of the adult budworms in late July and August.[14] These winds disperse budworm populations over wide areas along the eastern slopes of the Rockies.

8. "Red belt" phenomenon, particularly prevalent in Montana, causing winter drying--the desiccation and subsequent killing of the needles of coniferous trees exposed to short periods of warm temperatures in midwinter. Vegetative buds may be killed, but often they survive. When they do, the surviving host trees have proved to be poor sources of food for the budworm in the years immediately following the phenomenon. Budworm populations drastically diminished over wide areas of the Helena and Gallatin National Forests from "red belts" that developed during the winter of 1942-43 (*U265*, *U266*).

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[12]Raymond Granger, Radar Meteorologist, U.S. Department of Commerce, National Weather Service, Missoula, Mont. Personal communication; interpretation of weather records.

[13]News reports of the mass moth flight into the city of Helena, Montana, by the (Helena) Independent Record, August 4 and 17, 1951, described the invasion:

> The...(budworms) covered neon signs, downtown store windows, street lights and anything else that shone. Persons leaving the carnival grounds... appeared to have swarms of bees hovering around their heads...One large Ferris wheel...was almost obliterated....Persons driving into Helena from higher elevations could observe a haze over the business district and when they came closer they could see it was the insect invasion....Siebrand Bros. carnival, boasting "the world's largest neon midway," had to shut down and city streets swarmed with the insects which blackened the downtown district's neon signs.

[14]Robert G. Baughman, Research Meteorologist, Intermountain Forest and Range Experiment Station, Missoula, Mont. Personal communication.

Dodge ([illegible]) reared and identified insect parasites from budworm populations at five widely scattered locations in Montana from 1956 to 1959. He studied the singular or cumulative effect of one or several parasites in reducing populations of the budworm at these sites. The most numerous and effective parasites of the budworm in these forests then could be divided into four groups, depending upon the metamorphic stage of the budworm that was attacked (table 18):

Some data about the general abundance of the parasites and the interpretation made of their meaning by the Montana study are given here.

1. The greatest parasitism measured was that of hibernating instar II budworm by *Glypta fumiferanae* (Viereck) (Hymenoptera, Ichnuemonidae) and *Apanteles fumiferanae* Viereck (Hymenoptera, Braconidae). From 6 to 48 percent of this budworm stage was parasitized by the combined attacks of these two hymenoptera; *Glypta* predominated.

2. Decline of populations of *Glypta* and *Apanteles* during the study was attributed to moıtality from secondary insect parasites.

3. Parasitism of budworm eggs by *Trichogramma minutum* Riley (Hymenoptera, Trichogrammatidae) on two of five plots in 1957 and 1959 varied from almost 9 to 22 percent; on the remaining plots in those years, it averaged only 0.4 percent. Apparently this parasite was not important as a budworm control agent during the study.

4. Parasitism of budworm pupae by *Phaeogenes hariolus* (Cresson) (Hymenoptera, Ichneumonidae) ranged from 0 to 23 percent.

5. Tachinid parasites proved to be unimportant, possibly because a second yearly generation of these flies requires an alternate host, which may have been sparse in the study areas.

6. Aggregate parasitism by the four groups of budworm parasites ranged from 22 to 51 percent.

The parasitoids identified by the Montana study had performed similarly against the western spruce budworm in British Columbia (*117*), Oregon (*17*), and Colorado (*34*).

There are no reports of outbreaks of this budworm having been controlled by entomophagous parasites in either the Northern or the Intermountain Region. One instance of such biological control was documented from the Pike National Forest in Colorado in 1963. There a relatively unimportant parasitic wasp, *Bracon politiventris* Cushman (Hymenoptera, Braconidae), along with other probable parasitoids, was credited by McKnight ([illegible]) with the sudden collapse of a budworm infestation destined for imminent treatment with aerially applied insecticides.[15]

Predation of the western spruce budworm by birds has been observed and reported several times, but the amount of mortality that developed was never determined.

In 1931, the supervisor of the Nezperce National Forest reported that "grosbeaks, flycatchers, and other small birds increased very materially and seemed to have been instrumental in checking the spruce budworm" (*U257*). In 1942, from 300 to 400 crows were observed feeding on budworm moths in Douglas-fir forests along Battle Ridge in the Gallatin National Forest ([illegible]). Red squirrels, golden-mantled ground squirrels, and chipmunks have been observed preying on budworm larvae in Douglas-fir foliage in western Montana (*81*).

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[15]R. H. Hamre. The case of the dying budworms. Empire Magazine of The Denver Post, p. 37 and 39, Dec. 1, 1963.

Neither Region has reported significant reductions in budworm populations resulting from insect pathogens.

Starvation is a common, but as yet unevaluated, agent for natural control of the budworm. In many prolonged severe outbreaks, feeding has been so intensive that successive generations of the insect have had progressively less food. In other outbreaks, epidemic populations of the budworm have competed unsuccessfully for food that was being, or had been, consumed by other foliage-feeding insects or had been destroyed by foliage-infecting fungi.

The spruce coneworm, *Dioryctria reniculella* (Grote) (Lepidoptera, Phycitidae), another defoliator, often feeds on the same new needle growth of Douglas-fir trees in Montana that the budworm is feeding on. We have observed and measured populations of the coneworm on the Beaverhead National Forest that exceeded in number those of the budworm that were being treated with DDT for control.

Other defoliating insects that occasionally compete with the budworm for food are the black-headed budworm, *Acleris variana* Fernald (Lepidoptera, Tortricidae), on Douglas fir, grand fir, Engelmann spruce, and western hemlock; the Douglas-fir tussock moth, *Hemerocampa pseudotsugata* McDonnough (Lepidoptera, Lymantriidae), on Douglas-fir, grand fir, subalpine fir, white fir, and Engelmann spruce; the larch bud moth, *Zeiraphera griseana* (Hübner) (Lepidoptera, Olethreutidae), on western larch, Douglas-fir, and Engelmann spruce; and the larch casebearer, *Coleophora laricella* (Hübner) (Lepidoptera, Coleophoridae), on western larch.

Outbreaks of the spruce spider mite, *Oligonychus ununguis* (Jacobi) (Acarina: Tetranychidae), sometimes run concurrently with those of the budworm in Douglas-fir forests; both the mite and the budworm destroy food needed by the other.

Infectious outbreaks of *Rhabdocline pseudotsugae* Sydow on Douglas-fir and *Hypodermella laricis* Tubeuf on western larch, two needlecast fungi (Ascomycetes), periodically damage or destroy foliage needed as food by the budworm.

CHEMICAL CONTROL OF BUDWORM OUTBREAKS

One of the first attempts to suppress an epidemic population of the western spruce budworm also was the first use of a chemical insecticide to control this pest. This pioneer effort continued from 1929 through 1932 to control a budworm outbreak in Cody Canyon (Wapiti Valley), Shoshone National Forest, Wyoming.[16] The program was unique in several other respects: (1) its experimental use in 1929 of a lead arsenate-fish oil-water formulation as a budworm larvicide (*U66, U211*); (2) its experimental use of the same toxicant to inhibit oviposition (*U73*); (3) its use of white petroleum (Volck) oil as an experimental ovicide (*U70*); (4) its use of high pressure hoses and nozzles to spray the toxicant into tree crowns from the ground (fig. 22) (*U66, U211, U70*); and (5) its objective--to preserve the life and foliage of the host trees as a means of maintaining the Canyon's outstanding scenic qualities (*U66*).

The infestation, first reported in July 1922, was only partially controlled by the chemical because natural control agents began to take effect about 1930 to bring about its termination in 1932 (*U73, U74*).

Not until 1952 was a chemical insecticide used to control an outbreak of the budworm in this northern Rocky Mountain country. In that year, the authors were assigned the task of designing and supervising the aerial application of the chlorinated hydrocarbon insecticide, DDT, to 12,000 acres of budworm-infested Douglas-fir forests in the Sula Ranger District of Bitterroot National Forest (fig. 23) (*U106, U113*). This initial undertaking was essentially a trial of the effectiveness of the insecticide, of aerial dispersal techniques, and of entomological and administrative procedures previously developed in New York, Idaho, and Oregon (*35, U57, U95*).

Since then, the Forest Service has used aerially applied chemical insecticides in 25 experimental and 30 operational programs to control epidemic populations of the budworm on 6,338,600 acres of host forests in 15 National Forests and in lands administered by other Federal agencies within the northern Rocky Mountain area (table 19).

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[16]The Shoshone National Forest is part of the Rocky Mountain Region (Region 2 of the USDA Forest Service, but was then under the entomological jurisdiction of the Forest Insect Laboratory of the Bureau of Entomology (later called bureau of Entomology and Plant Quarantine) at Coeur d'Alene, Idaho.

Figure 22.--The first known use of a chemical insecticide to control an outbreak of western spruce budworm was this spraying of lead arsenate-fish oil emulsion from high pressure hoses in Cody Canyon, Shoshone National Forest, Wyoming, in July from 1929 through 1932. Under guidance by entomologists from the Forest Insect Laboratory of the Bureau of Entomology at Coeur d'Alene, Idaho, this spray program was undertaken to prevent defoliation and killing of Douglas-fir trees in a heavily used recreation area.

gure 23.--The first aerial application of chemical insectide for control of western spruce budworm in the Northern and Intermountain Regions was this dispersal of DDT over budworm-infested Douglas-fir trees in the east fork of the Bitterroot River, Bitterroot National Forest, July 1952.

Operational Control Programs

The objective of operational control programs was to reduce populations of the budworm to endemic levels in specific host forests where there appeared to be immediate danger of heavy mortality of trees. This was attempted by spraying the infested forests with prescribed dosages of chemical insecticides from low-flying aircraft. The programs followed biological guidelines that described techniques and procedures required to achieve acceptable reductions in the budworm populations to be treated (*U100*, *U116*, [illegible], [illegible]).

Administrative guidelines were also prepared to assure effective compliance with fiscal and procurement requirements; assignment, training, and supervision of personnel; spraying procedures; and safety precautions, which were part of every program (*U273*, [illegible], [illegible]). These guidelines were usually prepared by staffs of the two Forest Service Regional Offices in Missoula and Ogden, or by those of individual National Forests with the assistance of the Regional staffs.

After many operational control programs were completed, project personnel prepared detailed reports that described the biological effectiveness of the work (*U35*, *U49*, *U113*) or the operational accomplishments (*U17*, *U288*).

Preparation of technical specifications for aerially dispersing chemical insecticides to control the budworm depended heavily between 1952 and 1957 on reports of results of experiments in widely scattered sections of the country and from eastern Canada, some relating to the spruce budworm (*C. fumiferana*):

1. Airplane types and spraying apparatus (*35*, *U1*, *U2*, *U57*, *U95*, *U105*).

2. Effective widths of spray swaths (*35*, *U2*, *U57*, *U95*, *U105*).

3. Height of spraying above forest canopies (*26*, *35*, *U1*, *U2*, *U34*, *U36*, *U57*).

4. DDT formulations and dosage rates (*26*, *U1*, *U57*).

5. Spray droplet size (*26*, *U1*, *U105*).

6. Assessment of spray deposits (*25*, *67*, *68*, *69*, *70*, *95*, *U1*, *U2*, *U95*, *U105*).

7. Meteorological limitations (*U1*, *U2*, *U57*, *U95*).

The decision whether to proceed with spraying programs for budworm control usually depended upon biological and economic justification by informed entomologists and forestry resource managers. The need for controlling specific infestations was most often determined from these evaluations:

Biological Justification

1. Verifying the presence of epidemic populations of budworm.

2. Determining the probable trend of these populations after evaluating the effectiveness of natural population control agents that were present.

3. Ascertaining that epidemic populations of the budworm could be reduced to acceptable endemic levels for 1 or more years by proper application of a selected insecticide that had been registered for such use by appropriate Federal and State authorities. This determination implied that the recommended insecticide was highly toxic to the budworm in approved dosage, relatively nontoxic, or acceptably less so,

to nontarget terrestrial and aquatic insects, other animals, and vegetation, or to persons handling the compound or inhabiting the immediate environs of the proposed treatment area. Also, that practical methods were available for dispersing the insecticidal material over the forest at the recommended dosage.

Economic Justification

1. Evaluating the cumulate and predicted damage to the host trees and forests.

2. Determining the point at which this damage to the inherent uses and resources of the infested forests becomes intolerable.

3. Weighing the cost of spraying against the monetary or social values of the resource to be saved.

4. Assuring that funds, manpower, equipment, and time were available to conduct the proposed programs properly.

Operational budworm control programs between 1953 and 1958 were designed and performed under the concept of "entomological control units." A generally accepted hypothesis among specialists in insect control, this implied that satisfactory reduction of epidemic insect populations could best be accomplished by treating entire infestations or infested host areas. Boundaries of these control units were either the demarcation between epidemic and endemic populations of the pest insect or the perimeter of the host type. Assuming that control treatment could restore endemic populations, the concept supposedly prevented or delayed reinfestation of the treated area for a reasonable time from untreated populations of the insect that might be present outside the unit. It appeared to be workable in the two Forest Service Regions because mountainous terrain created mosaics of host and nonhost forests and of forested and nonforested lands.

Unfortunately, the theory did not work well here. In most outbreaks, there were not enough control dollars to treat all of the extensive acreage of infested host forests that confronted operation planners. Too many control dollars were necessarily deployed to areas of light infestation where budworm populations and host tree damage were minimal, while other areas, which had exceedingly dense populations or heavy host damage, went untreated.

Beginning in 1958, more effective use of limited control funds was achieved by adopting a system of "partial unit control" (*U51, U97*). Under it, aerial spraying to control budworm populations was directed to those areas where most of the host trees were in imminent danger of dying if exposed to further infestation. Control programs that used this system have undoubtedly prevented the killing of thousands of host trees that might not have been saved under the whole unit method of treatment.

Techniques of aerial spraying for forest insect control were originally designed to use small single-engine airplanes. They were relatively safe for the low-altitude flying needed to deposit spray materials on specific targets at the proper dosage. When well powered, these planes were maneuverable enough for similar performance over mountainous terrain.[17] However, the limited capacities of their spray tanks and slow airspeeds were disadvantageous at times. Their frequent return to airstrips for spray refills was both nonproductive and costly. Extensive operational control projects using large numbers of these small aircraft were often saddled with monumental problems of traffic control at airstrips or established airports.

[17]These same small-plane performance standards have been achieved since 1947 in the two Regions by Ford tri-motor and C-47 twin-engine airplanes when flown by competent mountain pilots.

Commencing about 1955, the two Regions employed larger, faster, single- and multi-engine airplanes (TBM, B-17, PBY, etc.) to increase spraying production without proportionately increasing spraying costs. Spraying production drastically improved, but not without some compromise in the biological effectiveness of some control programs.

Being less maneuverable, the larger, faster planes necessarily maintained higher average spraying heights over rough terrain. This increased the chances of spray drifting and consequent erratic spray deposition, which sometimes adversely reduced budworm control and created hazards to other parts of the environment.

Studies were conducted by personnel of the Forest Insect Laboratory at Beltsville, Maryland, in the Deerlodge National Forest in 1956 and 1957 to resolve the question whether effective budworm control could be achieved from spray released higher than the recommended 200-400 feet over treetops. Data from the 1956 study indicated that insecticide released from a height of 750 feet above host forests reached the tree crowns in greater amounts than spray released from 500 or 250 feet. Budworm mortality seemed to be more nearly uniform over the areas where spray was dispersed from the 750-foot height (*U36*). However, a more careful trial of spraying at the 750-foot height over a 30,000-acre tract in 1957 produced irregular patterns of budworm mortality that were deemed unsatisfactory by standards then imposed. Because of this, the research team recommended that spraying be done at lower heights to assure maximum effectiveness (*U37*).

The presumed superior performance of small spray planes was refuted by flight tests in the Salmon National Forest in 1965. Flight characteristics and spraying patterns of the small planes (Stearman and CallAir) were compared with those of a former U.S. Navy TBM high-powered single-engine airplane commonly used for aerial spraying in both Forest Service Regions (*U194*). In addition to their inability to spray as much area as the TBM in the same amount of time, the small planes were faulted for their (1) higher average height of spraying, (2) more erratic spray swath patterns, (3) lack of reserve power to pull out of canyons having cramped flying space, and (4) more spraying time lost during frequent maneuvering to higher altitudes for pilot reorientation.

The Forest Service used aerially applied DDT for budworm control between 1952 and 1964 because no other chemical insecticides were as biologically effective, as reasonable in cost, as easily available, or as safe to use. Initial and continued use of DDT was based on (1) satisfactory experience with the compound's insecticidal qualities from New York (*U57*), eastern Canada (*U1*), and Oregon (*11, 35, U18*), and (2) satisfactory operational experience gained from spraying 2,260 acres of forest land in Oregon in 1945 (*78*) and 413,500 acres in Idaho in 1947 (*U95*).

Budworm control programs during 1952-1964 used a 12-percent DDT-oil solution that dispersed 1 pound of DDT in 1 gallon of the mixture per acre. The following formulation was most frequently used:

DDT (Dichlorodiphenyltrichloroethane), technical grade	1 pound
Hydrocarbon solvent	1.2 quarts
Fuel oil, diesel Type A, to make	1 gallon

This formulation was usually delivered to budworm control project airfields by commercial chemical suppliers in ready-to-use form. In the Intermountain Region, DDT formulations were usually mixed at the airstrip from which they were distributed.

In its report on the use of pesticides issued in May 1963, the President's Science Advisory Committee recommended that governmental agencies curtail use of persistent insecticides. Accordingly, the Forest Service turned to other insecticidal materials for controlling budworm outbreaks. The last time DDT was used against the budworm was in 1964 in the Salmon National Forest, when 485,870 acres of infested forest were aerially sprayed with 1 pound of the insecticide per acre. An additional 39,199 acres were sprayed with one-half pound of DDT per acre. Application of DDT at these two dosages achieved satisfactory reduction of budworm populations on 57 of the 62 spray blocks (*U206*).

Wildlife Protection Measures

Guidelines for operational budworm control programs usually were explicit in instructions to avoid spraying over defined areas deemed vital to human health and wildlife welfare. They outlined specific procedures for supervising spraying near these sensitive environments.

These precautionary measures included provisions for protecting honeybee colonies of commercial beekeepers in or near spray areas. Most beekeepers moved their colonies out of the vicinity of spray zones before spraying operations, or covered them during and immediately following spraying. Residual toxicity of DDT to honeybees normally persists from 3 hours to 1 day; malathion liquid sprays last from 3 to 7 hours (*115*).

The impact of DDT spraying on various constituents of the forest community was extensively studied in conjunction with several large-scale budworm control operations. Using the aerial spraying of a Douglas-fir tussock moth infestation in northern Idaho in 1947 (*U95*) as a model, pest control technicians from the USDA Forest Service and biologists from the Idaho and Montana fish and game departments investigated the effects of DDT residues on fish and animal populations following operational budworm control projects in 1956 and 1957 in sections of the Lewis and Clark, Helena, and Beaverhead National Forests and in several localities within the Salmon National Forest in 1963 and 1964 (*20, U35, U103*). Part of the investigations concerned with aquatic organisms were in streams flanked by nonspray zones 100 to 400 feet wide on either side of the waterways.

Data from these investigations supported several general conclusions concerning the effect of residues from the application of 1 pound of DDT per acre to budworm-infested forests:

1. Culinary quality of water from streams within or near spray areas was not impaired.

2. Natural or planted populations of trout, steelhead trout, and Chinook salmon were not harmed directly or from the buildup of DDT in fatty tissues.

3. Measurable amounts of DDT within spray zones immediately after spraying were not detected 1.5 miles downstream from these zones.

4. Aquatic invertebrate populations were drastically reduced by mortality within 24 hours after spraying; but there was natural restoration of these populations, in numbers if not in species, within 3 to 6 months or more after spraying.

5. Pre- and post-spray populations of forest birds on 40-acre plots were undifferentiated; this indicated neither mortality nor emigration from sprayed areas.

6. No acute losses of warmblooded animals were detected in or near spray zones.

7. Cream and grade A milk produced within and outside the spray zones showed no harmful amounts of DDT.

Even so, in some locales, fish, aquatic and terrestrial invertebrates, birds, and small animals were killed by their exposure to abnormally heavy quantities of DDT spray mixture. In these locales the toxicant was concentrated on vegetation, on the ground, or in streams and lakes from several spray plane crashes, from leaking spray plane nozzles over repeated flight routes, or from intentional dumping of spray loads by pilots who were experiencing in-flight malfunctions of their aircraft.

One most apparent and widespread ecological disturbance resulting from DDT spraying was the sudden appearance of epidemic infestations of the spruce spider mite. These epidemics first appeared in 1957 in Douglas-fir forests sprayed in 1956 to control budworm in parts of the Helena, Lewis and Clark, Deerlodge, and Beaverhead National Forests in Montana, and the Boise and Payette National Forests in Idaho (*56*, *U117*). Of the 885,000 acres of Douglas-fir type sprayed in Montana, 799,000 acres became infested with the mite in 1957. Of the 476,000 acres sprayed in 1956 in the two Idaho National Forests, 22,000 acres became mite-infested in 1957 (*U30*, *U278*). We believe that application of DDT, which is not toxic to the spruce spider mite, allowed its buildup by reducing populations of its effective predators. Chlorosis of host tree needles and the subsequent defoliation of host trees were at least as severe as much of the feeding damage caused by the budworm in the previous year.

The mite outbreaks spurred several surveys to determine the biology and abundance of mites in forest environments (*41*, *U96*). In response to the question whether use of DDT for budworm control should be continued, the Helena National Forest conducted an experimental spray program in 1958 using DDT and an acaricide, Genite, together to control the budworm and followup populations of the spider mite (*U119*). Results of the test were inconclusive because of the unforeseen collapse of spider mite populations from some natural cause.

These brief but spectacular outbreaks of the spruce spider mite attracted national and international interest of acarologists and forest insect control specialists. Rachel Carson (*19*) cited the occurrence of the spider mite outbreaks as one of a number of reasons for condemning DDT as an insecticide.

The decision in 1964 to stop using DDT for budworm control came at a time when outbreaks of this insect were exceptionally widespread. Epidemic infestations were tallied on 3.3 million acres of host types in the Northern Region and on 1.5 million acres in the Intermountain Region in 1965 (table 12). The need remained for protecting forest resource values in many parts of the infested acreage.

The organophosphate insecticide, malathion, was the first of several chemicals used to replace DDT for controlling the western spruce budworm. This nonpersistent insecticide was first applied experimentally at several dosage levels between 1963 and 1965 in parts of five National Forests in Idaho and Montana (table 19). Malathion was first used operationally in 1966 on 83,000 acres of budworm-infested Douglas-fir stands in the Beaverhead and Gallatin National Forests; it was sprayed at the rate of 13 fluid ounces per acre in its technically pure state without carrier (*U236*, *U288*).

The low-volume application of technical grade malathion in these two operational programs was done without benefit of spray deposit assessment from oil-sensitive dye cards or the planned use of the fluorescent tracer material, Leucophor C, which would have allowed the fine spray droplets to be traced and their deposits quantified. Since Leucophor C coagulated in mixture with the insecticide and clogged spray nozzles on the aircraft, it was omitted from the application. This difficulty has since been remedied.

Experimental Control Programs

Popular concern over ecology and environmental quality, so widely and energetically xpressed during the 1960's, brought reactionary changes in the chemical control of the udworm. Among them were (1) curtailment of use of the persistent, broad spectrum nsecticide, DDT; (2) accelerated field testing of substitute chemical insecticides ore specific to the budworm, short-lived, and less harmful to other animal components f the budworm ecosystems; (3) laboratory testing of the insecticidal pathogen, *acillus thuringiensis* Berliner (*U52*); (4) trials of new techniques for aerial spray ispersal; and (5) more exacting control of aerial spray deposits in or near environ-entally sensitive areas.

This last mentioned change was soon effected by recalling smaller aircraft to pray near the sensitive areas. Protection from spray residues was further increased y more stringent regulations for aerial spraying.

Other changes in control techniques quickly followed. By the mid-1960's, field esting in Montana was determining the effectiveness of newly developed aerially applied erosol mist sprays to reduce budworm populations (*52, 53, 54*). Fluorescent tracers ntroduced into spray formulations to trace the positioning and amount of the minuscule pray droplets were also tested (*52, U177*).

An important change in policy for the chemical control of the budworm during this ime was the decision by the Forest Service to find, test, and use insecticides that erformed as effectively as DDT, but that maintained safety of the environment. To mplement this, the Chemical Insecticide Evaluation Research Project was established n 1964 at the Pacific Southwest Forest and Range Experiment Station, Berkeley, alifornia. The Project's mission was to screen candidate chemical insecticides for ontrolling insect pests of forest trees.

The screening process includes laboratory and field testing of insecticides that ight prove to be (1) specifically toxic to a single target species, such as the bud-orm, (2) capable of quickly killing populations of that insect, (3) degradable to ontoxic substances within a few days after their application, and (4) adaptive to ow-dosage aerial dispersal (*112*).

New-generation insecticides selected for budworm control by the Project's initial creening were carbaryl (Sevin), dimethoate (Cygon), mexacarbate (Zectran), pyrethrins, alathion, phosphamidon, and naled (Dibrom) (table 20). These insecticidal compounds ere field-tested between 1964 and 1972 for their effectiveness in budworm control and or possible side effects in several National Forests in Idaho and Montana. Following s a summary of pertinent information yielded by these tests:

alathion (Organic phosphate)

Malathion was first field-tested in Montana in 1963. One pound of malathion in uel oil to make 1 gallon was applied at the rate of 1 gallon per acre. About this ime, entomologists working with agricultural insect pests were finding that low-volume pplications of technically pure malathion without solvents or carriers were effectively ontrolling epidemic populations of certain target insects. Beginning in 1964, similar ow-volume applications of malathion were tested on western spruce budworm populations n several National Forests in Montana and Idaho. They were also used in 1966 in two perational budworm control programs in Montana.

The following tabulation summarizes history of the use of malathion against budworm populations in the northern Rocky Mountain and Intermountain areas:

Year	National Forest	Malathion (Fluid oz/acre)	Fuel oil, to make (Gallons)	Budworm population reduction[1] (Percent)	References
1963	Bitterroot	16	1	85	
		16	2	85	*U173*
1964	Lolo	9	None	88	*U204*
		12	1	83	*U287*
	Helena	12	1	81	*U287*
1965	Lewis and Clark	9	None	88	
		13	None	88	*U203*
	Salmon	9	None	71	
		13	None	90	*U194*
1966	Gallatin	13	None	87	*U236*
	Beaverhead[2]	13	None	97	*U288*

[1]Percentages listed here have not been corrected to allow for natural mortality.
[2]Cooperative project with the Bureau of Land Management on BLM lands outside of the National Forest. Host species: Rocky Mountain Douglas-fir.

Maximum percentages of budworm mortality resulting from malathion spray deposits were computed from 2 to 10 days after some test spraying. Pattee (*U194*) suggested that final determination of budworm mortality be delayed until 10 or 12 days after spraying on large-scale control programs involving low-volume applications of malathion.

Without fuel oil as part of low-volume applications, it was not possible to use oil-sensitive dye cards (*24, 25, 95*) to analyze the distribution patterns and amounts of malathion spray droplets, or, from them, to compute the amount of insecticide being deposited. In place of the dye cards, some malathion spray tests planned to use known numbers of solid, insoluble, micron-size, zinc-cadmium sulfide, fluorescent particles mixed in suspension with the liquid malathion (*52, 56*). The particles in the spray deposits, visible under ultraviolet light, are indicators of insecticide deposition on artificial targets or on the sprayed budworm larvae. However, problems were encountered in using fluorescent substances. The fluorescent dye Fluoral 7GA used with low-volume malathion spraying in 1965 remained visible in deposits under ultraviolet light for only as long as 2 hours after spraying (*U194*). In 1966, use of the fluorescent particle substance Leucophor C, when mixed with technical grade malathion, created a sludge that clogged aircraft spray nozzles and other parts of the spray system (*U289*). Because of these problems, most of the low-volume spraying with malathion was done without knowledge of the number and size of the spray droplets. Adequate spray deposition depended almost wholly on good orientation by spray plane pilots and on close supervision of spraying operations by aerial observers. This presumably was effective because the budworm mortality achieved by most low-volume malathion spray projects was generally satisfactory.

Application of low-volume malathion, with or without oil carriers and without fluorescent tracers, cost approximately $1.50 per acre as used on nearly 250,000 acres in Montana and Idaho. Per-acre cost of similar spraying on two smaller projects totaling only 11,000 acres, however, averaged approximately $5.00.

Measurements or observations were made on each malathion spray program to determine the effects of the deposited insecticide on aquatic invertebrates and fish in streams within or near the spray zones and on song and upland game birds and animals in these zones. Data collected from these surveillances were often inconclusive because of poor experimental design, unforeseen weather phenomena, or erratic spraying.

The more substantial measurements indicated that low-volume malathion spraying, with reasonable avoidance of streams, caused (1) immediate but temporary drifting (attempt to leave a particular stretch of stream) and some killing of aquatic invertebrates, (2) little damaging inhibition of cholinesterase in fish, and (3) little observed stress or mortality of fish from malathion deposits that drifted, or were inadvertently sprayed, into the water of streams within the spray zones (*U194, U298, U299*).

Observations on the reactions or distress of song birds or animals from low-volume deposits of malathion spray were mostly inconclusive, albeit no adverse effects were recorded. Attempts to record adverse effects of the spraying on caged fish and pheasants were voided because the test animals died before the spraying.

Mexacarbate (Carbamate)

Laboratory tests by the Chemical Insecticide Evaluation Project indicated that the carbamate insecticide mexacarbate (trade name Zectran) was one of the most effective and ecologically acceptable of the present-day chemicals that might be used to control budworm.

Mexacarbate appears especially suited for this task because (1) it can produce high rates of mortality in budworm larval populations; (2) it is highly toxic against sixth-instar budworm larvae (100 times greater than DDT); and (3) it appears to have little adverse effect on forest environments because of its specificity to the budworm, its rapid rate of chemical detoxification after aerial application, and its relatively low hazard to aquatic and other terrestrial biological systems (table 20). Present disadvantages are its relatively high cost but, more important, its frequently unsatisfactory field performance, a residual life that probably is too short, and a rather low registered dose for the variable field conditions in which it is used.[18]

Additional studies of usefulness of mexacarbate indicated that it can be applied effectively in the field in small dosages and as aerosol sprays with droplets smaller than 50 microns median mass diameter (m.m.d.) (*53, 54, 55*).

Several formulations of mexacarbate were applied aerially by the USDA Forest Service between 1964 and 1971 in operation-simulated field tests in the Northern and Intermountain Regions. In addition to determining its toxic effectiveness at low-dosage rates, the tests evaluated the efficiency of spray plane bifluid systems using atomizing fluids for these low rates, for small droplet emissions, and for spray dispersal patterns. These tests also measured effectiveness of fluorescent tracers in spray formulations (*U177*) and of a neodymium lidar transmitter (*88, U34*) for detecting and quantifying the dispersal and placement of spray deposits.

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[18]Bohdan Maksymiuk, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Corvallis, Oregon. Personal communication.

Formulations most frequently used in these tests consisted of mexacarbate (technical grade) 2.4 ounces (0.15 pound) in one gallon of solution composed of a solvent (Dowanol TPM), 1 part, and a carrier (deodorized kerosene, or cycle oil), 9 parts. One gallon of this mixture was usually applied to each acre of infested forest.

The several experimental applications of mexacarbate reduced populations of budworm on National Forests in Idaho and Montana as shown below.

Year	*National Forest*	*Mexacrabate (Oz/acre)*	*Acres treated*	*Budworm Population reduction*[1] *(Percent)*	*References*
1964	Salmon	1.6	60	[2]NA	*U289*
1965	Bitterroot	2.4	1,080	92	*118*
1966	Salmon	2.4	4,860	[3]100	*U176*
	Bitterroot	2.4	5,360	[4]85	*U104*
1967	Sawtooth	2.4	2,300	94	*88, U7*
1968	Lolo	1.0	6,080	59	*U182*
1969	Nezperce	2.4	6,000	56	*U290*
1971	Nezperce	2.4	9,000	48	*30*

[1]Not corrected for natural mortality.
[2]Not available; reduction considered unsatisfactory.
[3]Natural budworm mortality 98 percent on unsprayed check area; test inconclusive.
[4]Natural budworm mortality 46 percent on unsprayed check area.

Disappointingly low budworm mortality from most of the above mexacarbate applications was attributed to (1) low-level budworm populations that increased the difficulty of statistically differentiating the abundance of prespray and postspray and of treated and untreated budworm numbers, (2) high natural mortality of budworm larvae at the time of spraying, (3) unseasonable rapid development of budworm larvae prior to spraying, (4) malfunctions of spraying equipment, or (5) poor distribution and placement of spray deposits.

Laboratory screening in Berkeley established the suitability of mexacarbate for budworm control on operational scale. But, as Dewey and others pointed out (*30*), its effectiveness depends on getting adequate deposits of the chemical to the target trees. Fluorescent tracers (*U177*) revealed wide variation in mexacarbate deposits both within and between target trees. The tracers also disclosed a good correlation between the amount of spray deposited and the amount of budworm mortality. This implies that good budworm mortality can be achieved with the small-micron spray droplets of mexacarbate where the spray is deposited in recommended amounts.

The low-dosage application of mexacarbate in the Nezperce National Forest in 1971 did not seriously reduce the abundance of major insect parasites of the budworm (*30*). The percentage of budworm larvae parasitized by *Apanteles fumiferana* increased slightly but significantly between prespray and 8-day postspray larval samples. Parasitizing by *Glypta fumiferana* and tachinids did not increase appreciably.

The specificity of mexacarbate to the budworm and two other forest pests was demonstrated by experimental spraying in the Bitterroot National Forest in 1965 (*118*). Mexacarbate reduced populations of larch bud moth (*Zeiraphera griseana*) and a sawfly (*Neodiprion* sp.) more than those of the budworm, but it did not greatly reduce populations of the western hemlock looper (*Lambdina fiscellaria lugubrosa*) and another unidentified looper.

The effects of aerial applications of mexacarbate on wildlife were surveyed on several of the pilot tests of this chemical. Fisheries biologists reported no apparent detrimental effects on populations of native trout after mexacarbate was purposely sprayed over a stream in the Bitterroot National Forest in 1966 (*U104*). They observed only slight increase in the number of drifting aquatic insects in the sprayed portion of the stream. In a nearby stream where a bordering forest strip had been sprayed by helicopter to reduce adverse effects of the chemical to fish and aquatic invertebrates, postspray drift of insects was as great as in the sprayed stream, but fish suffered no apparent ill effects.

A 240-acre study plot established as part of the 1966 Bitterroot National Forest mexacarbate test was sprayed on 2 consecutive days with five applications of 0.15 pound per acre of the chemical to observe possible effects of the toxicant on native grouse. Preliminary analysis of information developed by this test indicated no harmful effects to grouse during or following application (*U104*).

Wildlife research biologists studied the reactions of birds and mammals to experimental spraying of mexacarbate in the Bitterroot National Forest in 1965 and 1966, in the Salmon National Forest in 1966, and in the Sawtooth National Forest in 1967. The first three treatments were aerial spraying of 2.4 ounces of mexacarbate in 1 gallon of oil carrier per acre. The Sawtooth study used an aerosol spray of 1 ounce of mexacarbate in 1 pint of oil carrier per acre.

The biologists reported that 3 years' study of mexacarbate residues showed no detrimental effects on wildlife (*81*), but added that the studies did not prove safety in the use of this chemical. They also observed that:

1. The mexacarbate applications resulted in no harm or reduction in birds or mammals in the areas studied.

2. The spray temporarily increased the availability of budworm larvae and other insect food.

3. The reduction in the insect food supply that followed this increase did not cause nest abandonment or interfere with the rearing of young birds.

4. Only one chipmunk showed any effect that could be attributed to the spray--a temporary but marked increase in respiration on the day of spraying.

5. Several golden-mantled ground squirrels taken the day after the spraying had stomachs packed with budworm larvae; one contained at least 179 larvae.

6. During the summer of 1966, both red squirrels and chipmunks were apparently foraging for budworm larvae at the tips of Douglas-fir branches.

7. Ground squirrels, chipmunks, and a deer mouse collected within a day after spraying on one study area had fluorescent particles from the spray in their pelage and intestinal tracts; all contained some budworm remains, but the chipmunks contained the most.

Phosphamidon (Organic Phosphate)

Five thousand acres of privately owned budworm-infested Douglas-fir forest in the Blackfoot River drainage of western Montana were sprayed with a water emulsion of phosphamidon in 1963 ([illegible]). A cooperative undertaking by the USDA Forest Service and Anaconda Forest Products, owner of the timberlands, was an experimental application designed to determine (1) the practical effectiveness of the insecticide on the budworm, (2) its toxicity to stream habitat invertebrates and trout, and (3) the possible correlation between the number of spray droplets deposited on sample dye cards and the mortality of budworm larvae on nearby host tree foliage.

The rapid hydrolizing and metal corrosive actions of phosphamidon required that formulations of the insecticide be limited in amount to the equivalent of one spray plane load at a time, about 350 gallons. The following formulation was used, in the order of the listed ingredients:

Water	311 gallons
Methylene blue dye	35.5 grams
Sodium bisulphate, to lower the pH of the water from 7.8 to 7.6	2.7 ounces
Phosphamidon, technical grade, liquid	39 gallons

This mixture, sprayed over the test forest at the rate of 1 pound of phosphamidon per acre, reduced larval populations of the budworm by 71 percent as measured 4 days after spraying. This percentage of budworm mortality was considered inadequate.

Stream bottom and drift samples indicated no measurable loss of aquatic invertebrates inside of or downstream from the spray zone. Rainbow and cutthroat trout in live cars above, within, and below the sprayed area suffered no apparent distress or mortality.

Blood samples from several grouse found dead within the sprayed area showed evidence of organic phosphate poisoning. Grouse in a stupefied condition, presumably from effects of the insecticide, were easily captured in the same area; but other grouse observed in the spray zone appeared to be healthy and unaffected by the spray. Forest-inhabiting birds in the sprayed area were estimated by a wildlife biologist to be about one-fourth those observed prior to spraying.

Terrell (*U227*) found no correlation between the number of spray droplets deposited on sample dye cards and the amount of budworm larval mortality on surrounding Douglas-fir foliage. Maksymiuk *(69)* also observed this negative relationship after using a DDT-oil spray in tests in Montana and Maine.

Only authorized personnel in special protective clothing were allowed at the insecticide mixing facility at the airfield because of the high toxicity of phosphamidon.

Carbaryl (Carbamate)

The carbamate insecticide carbaryl, known by its trade name Sevin, was field-tested on 9,960 acres of budworm-infested Douglas-fir in the Targhee National Forest during July 1963 (*111*, *U286*). Since carbaryl had been effective against other forest insect pests elsewhere, it was important to learn its action against the budworm. Specifically, the trial of this relatively new toxicant was undertaken to determine its ability to reduce epidemic populations of the budworm when aerially applied at dosage rates of 1.6 pounds and 0.8 pound in 1-1/2 gallons of water per acre.

The water-soluble fluorescent dye tracer Leucophor C was added in the amount of percent of the carbaryl-water spray mixture. The dye was used in addition to spray leposit cards to measure spray deposition. The test was inconclusive because most of he water-soluble carbaryl was apparently washed from the foliage of sprayed trees by ieavy thundershowers shortly after its deposition. In the short interval between the praying and the rainstorm, no appreciable knockdown of budworm larvae was observed. 'ostspray sampling showed that larval populations were virtually equal to prespray opulations.

Fluorescent particles presumably washed from tree foliage by the rains were eadily detected on the forest floor. Their sparseness along a streambank indicated hat efforts to keep the spray out of the water apparently had been successful.

imethoate (Organic Phosphate)

Dimethoate, a candidate insecticide for controlling the budworm, was aerially pplied in the South Fork Iron Creek drainage of the Salmon National Forest in July 964 (*U6, U175*). A formulation of one-fourth pound of the toxicant in 1 gallon of cycle il was applied at the rate of 1 gallon per acre over 1,080 acres of Douglas-fir trees. nsecticidal action of the dimethoate was slow, as evidenced by a lack of immediate ostspray knockdown of budworm larvae and the absence of distressed or dead larvae on he ground under sprayed trees for 5 or 6 days after spraying.

The increasing percentages of mortality of budworm larvae reported from 5 to 20 lays after spraying may be attributed to possible systemic action of the dimethoate, s follows:

Postspray sample period	*Larval mortality*
	(Percent)
5th day	37
10th day	44
15th day	44
20th day	56

These low percentages of larval mortality were inadequate reduction of budworm opulations.

aled (Organic Phosphate)

The organophosphate insecticide naled was tested for capability to reduce budworm opulations by spraying on 1,165 acres of host forests in the Mud Creek drainage of itterroot National Forest in July 1965 (*118*). Naled was applied in a low-volume concentrate in ethylene glycol at the rate of 0.41 pound (0.82 pint of the toxicant) per cre from a helicopter.

Since naled is less persistent than DDT,[19] it was hoped that this test would show t to be highly effective against all larval instars of the budworm at the time of praying to match the overall effectiveness of DDT. This effectiveness was not chieved. Postspray samples of sixth-instar larvae showed less mortality than treated arvae in the fourth and fifth instars.

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[19]Residues of DDT applied aerially during the fourth larval instar of the budworm ave remained highly toxic for a week or more. Their toxicity is therefore effective gainst larvae of the current generation emerging late from diapause. They may still e toxic to first-instar budworm larvae of the succeeding generation (*118*).

The average percentage of budworm mortality from naled sprayed on three host tree species was:

Tree species	*Budworm larval mortality (Percent)*
Subalpine fir	62
Douglas-fir	34
Engelmann spruce	73
All species, weighted	43

Pyrethrins (Organic, Botanical)

Pyrethrins, which are excellent insecticides, are derived from pyrethrum flowers of the genus *Chrysanthemum*; they may also be synthesized from other chemicals.

Three formulations of a pyrethrin compound were applied to as many 20-acre test plots in the Williams Creek drainage of the Salmon National Forest in July 1964.[20] The insecticide presumably was deposited on budworm-infested Douglas-fir trees by helicopter and fixed-wing aircraft. The formulations used and the budworm larval mortality attributed to each were:

Pyrethrin formulation and dosage per acre	*Budworm larval mortality (Percent)*
1. Pyrethrins, 0.03 pound, in water, 2 gallons per acre, applied as an invert emulsion	0-19
2. Pyrethrins, 0.01 pound, in #2 fuel oil, 1 gallon per acre	11-48
3. Pyrethrins, no amount recorded, in water, 2 gallons per acre	0-18

Observations indicated that drifting of the spray may have caused much of the insecticide to be deposited outside of the plot areas.

Dichlorovos (DDVP) (Organic Phosphate)

A formulation containing 0.1 pound of dichlorovos in 1 gallon of #2 fuel oil was applied by helicopter at the rate of 1 gallon per acre on a 20-acre sample plot in the Williams Creek drainage in Salmon National Forest in July 1964 to test its insecticidal value on a larval population of the budworm. The application did not reduce the larval population on the sprayed area.

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[20] Galen C. Trostle, Entomologist and Head, Section of Forest Insect Control, Division of Timber Management, USDA Forest Service, Intermountain Region, Ogden, Utah. Personal communication.

PROSPECTS FOR FUTURE OUTBREAKS

Ranger district reports of outbreaks, continuing infestation, and experiments devised to develop effective controls for the western spruce budworm have provided abundant useful information that covers 50 years. Despite the numerous studies and experiments, though, we face two unpleasant facts: the budworm is still rampant, and nearly 5 million acres of forests in the northern Rocky Mountain area are still infested.

Foresters and entomologists have been collecting information about biology and control of this budworm during five decades, but we are still hunting for effective ways to prevent sudden devastating outbreaks and for infallible methods for controlling outbreaks that may occur--methods at once biologically effective and ecologically acceptable. We do not know precisely what conditions trigger outbreaks, keep them going, or terminate them. We have not learned to recognize these conditions or measure their magnitude in time to be at least forewarned of impending explosions of populations of this insect. In short, we simply do not know when or where the next outbreaks will appear nor what their impact is likely to be on the varied resource values of the host forests.

Review of the long record of past outbreaks reveals absence of several kinds of information that could be supplied by concerted effort in research by pest control entomologists--information that would enable forest managers in the West to prevent massive outbreaks of the budworm or to reduce the impact of any that might occur. These two objectives could be achieved:

1. Through more knowledge of the biological and environmental factors that affect the population dynamics of the budworm, and through means of monitoring these factors in localities where outbreaks are presumed most likely to occur.

2. Through recognition of conditions in host forests that foster and support the development and maintenance of epidemic budworm populations for abnormally long periods, along with effective methods and the capital needed to regulate these conditions so as to reduce the susceptibility of these forests.

3. Through development of adequate methods for evaluating the economic and ecologic impacts of budworm outbreaks on the multiple or single uses for which individual forests are managed; these evaluations, in turn, to be bases for management decisions that must consider long-term preventive control or current applied control measures.

4. Through availability of assured, standardized techniques for subduing current outbreaks; these techniques to be operationally feasible and subject to controls that at once guarantee their biological effectiveness and preserve the normal harmony of forest ecosystems.

5. Through clearer realization by forest managers of the biological complexity and the general importance of budworm control.

We feel that attainment of these objectives within a reasonably short time is necessary if the management of forests in the northern Rocky Mountain area is to proceed uninterrupted by occasional devastating outbreaks of the budworm.

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APPENDIX

(Tables 1-20)

able 1.--*Earliest recorded outbreaks of the western spruce budworm in National Forests in the Northern and Intermountain Regions, USDA Forest Service, and in Yellowstone National Park, 1922-1934.*

State	National Forest or Park	Years reported[1]
	NORTHERN REGION	
daho	Bitterroot	1926-28; 1930-31
	Coeur d'Alene	1924; 1928-31
	Kaniksu	1922-24
	Nezperce	1924-33
	St. Joe	1927-28
	Selway (now Clearwater)	1924-34
	Selway (now Nezperce)	1926-34
ontana	Absaroka (now Gallatin)	1925-26
	Beaverhead	1925
	Bitterroot	1927
	Gallatin	1925-34
	Helena	1925-34
	Madison (now Beaverhead)	1925-29
yoming	Yellowstone National Park	1922-25
	INTERMOUNTAIN REGION	
daho	Boise	1922-24; 1927; 1929-31
	Lemhi (now Challis)	1923-24
	Sawtooth	1924; 1927; 1930
	Targhee	1927
	Weiser (now Payette)	1922-24; 1927; 1929-31
yoming	Bridger	19[illegible]
	Teton	1923-24
tah	Cache	1927
	Uinta	1924
	Wasatch	1924
evada	Humboldt	1931

[1]See tables 4, 5, and 6 for documentation of specific outbreaks.

Table 2.--*Infestations by the western spruce budworm reported annually from National Forest Ranger Districts in the Northern Region, USDA Forest Service, 1922 through 1953*[1]

National Forest	Ranger district	1922-1930	1931-1940	1941-1950	1951-1953
		IDAHO			
Bitterroot	Magruder	----XXX-X	X--XX-----	----------	---
Clearwater	Bungalow	---------	-XX-------	----------	---
	Canyon	-------X-	----------	----------	---
	Lochsa	----XXXXX	XXXX------	----------	---
	Pierce	------XXX	X---------	----------	---
	Powell	--XXXXX--	---------	-----XXXXX	XXX
Coeur d'Alene	Kingston	--X---XXX	XXX-------	----------	---
	Magee	-------X-	----------	----------	---
	Wallace	---------	----------	X---------	---
Kaniksu	Priest Lake	XXX------	----------	----------	---
	Trout Creek	---------	----------	X---------	---
Nezperce	Clearwater	---XXXXXX	XXXX---XXX	XXXX------	---
	Elk City	----XXXX-	----------	----------	---
	Moose Creek	----XXXXX	XXXX------	----------	---
	Red River	--XXXXXXX	----------	----------	---
	Salmon River	----X----	----------	----XXXXXX	XXX
	Selway	----XXXXX	XXXXXXX---	----------	---
	Slate Creek	----XXX--	----------	----------	---
St. Joe	Avery	-----XX--	----------	----------	---
	Palouse	------X--	----------	----------	---
		WYOMING-MONTANA			
Yellowstone Natl. Park	North	XXXX-----	----------	----------	XXX
		MONTANA			
Beaverhead	Lima	---------	----------	--------X-	---
	Madison	-----XXX-	----------	X---------	--X
	Sheridan	---XX----	X---------	----------	---
	Wisdom	---X-----	----------	----------	X--
Bitterroot	Stevensville	-----X---	-------X--	----------	---
	Sula	---------	----------	----------	XXX
	West Fork	---------	-------X--	----------	XXX
Custer	Beartooth	---------	----XXXXXX	----------	---
Deerlodge	Boulder	---------	----------	----XXXXXX	XXX
	Deerlodge	---------	----------	----------	XXX
	Philipsburg	---------	----------	----------	XXX
	Whitehall	---------	----------	----XXXXXX	XXX

(con. next page; for footnotes see end of table)

Table 2. (con.)

National Forest	Ranger district	1922-1930	1931-1940	1941-1950	1951-1953
		MONTANA (con.)			
Flathead	Big Prairie	---------	----------	--XXXXXXXX	XX-
	Condon	---------	----------	------XXXX	XXX
	Coram	---------	--X-------	-----X----	---
	Spotted Bear	---------	----------	-XXXXXXXXX	XX-
	Swan Lake	---------	----------	-----X-XXX	XXX
Gallatin	Big Timber	---XX----	----------	----------	---
	Bozeman	-----XX--	-XXXX-XX--	XXXXXXXXXX	XXX
	Gardiner	---X-----	----------	----------	XXX
	Hebgen Lake	---------	----------	-X--------	---
	Livingston	---X-XXXX	XXXXX-XX--	--------XX	XXX
Helena	Canyon Ferry	--------X	XX--------	----XXXXXX	XXX
	Helena	---------	----------	----XXXXX-	---
	Lincoln	---------	----------	----------	XXX
	Townsend	---XXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXX
Kootenai	Fortine	---------	--------X-	----------	---
Lewis & Clark	Belt Creek	---------	----------	------X---	---
	Judith	---------	----------	------X---	---
	Musselshell	---------	-XXXX-XX--	-----X-X-X	XXX
	Sun River	---------	----------	---------X	---
	Teton	---------	-------X--	---------X	---
	White Sulphur Springs	---------	----------	---XX-X-XX	XXX
Lolo	Bonita	---------	----------	-------XXX	XXX
	Seeley Lake	---------	-------XXX	X----XXXXX	XXX
	Superior	--------X	----------	----------	---
Glacier Natl. Park	Hudson Bay	---------	----------	-----XX---	---
	West Lakes	---------	----------	-----XXX-X	XX-

[1] X, budworm infestation within the District. Districts from which no infestations were reported during the 32-year period are not listed.

Table 3.--*Number of years outbreaks of the western spruce budworm were reported from administrative units[1] within the Northern and Intermountain Regions, 1948 through 1971*

State	Administrative unit	No. years outbreaks reported
	NORTHERN REGION (21 years: 1948-56; 1960-71)[2]	
Washington	Colville	1
	Kaniksu	2
Idaho	Bitterroot	9
	Clearwater	13
	Coeur d'Alene	0
	Kaniksu	1
	Nezperce	17
	St. Joe	3
	Craig Mountain (private)	12
Montana	Beaverhead	16
	Bitterroot	17
	Custer	6
	Deerlodge	19
	Flathead	11
	Gallatin	18
	Helena	21
	Kootenai	0
	Lewis & Clark	16
	Lolo	18
	Garnet Range, BLM	12
	Judith Mts., BLM	6
	Centennial Valley, BLM	1
	Sweetwater Hills, BLM	1
	Glacier Natl. Park	3
Wyoming	Yellowstone Natl. Park	17
	INTERMOUNTAIN REGION (22 years; 1950-71)	
Idaho	Boise	20
	Caribou	5
	Challis	14
	Payette	19
	Salmon	16
	Sawtooth	17
	Targhee	16
Utah	Ashley	3
	Cache	0
	Dixie	0
	Fishlake	3
	Manti-LaSal	0
	Uinta	0
	Wasatch	0
Wyoming	Bridger	7
	Teton	5
Nevada	Humboldt	0
	Toiyabe	0

[1]All units are National Forests unless designated BLM (Bureau of Land Management) or named as National Parks.

[2]Not reported by individual National Forests, 1957-59.

Table 8.--Infestations by the western spruce budworm reported by District Rangers in National Forests of the Northern Region from 1922 through 1953

National Forest[1]	Year	Ranger district[2]	Infested acreage[3]	Host tree species[4]	Pertinent infestation conditions, reporter, and references[5]
					WASHINGTON
Colville					No infestations reported
					IDAHO
Bitterroot (Nezperce)	1926	Magruder (Paradise)	NR	ES,DF	White Cap Cr., Canyon Cr., Selway R.; an estimated 300 trees are killed in these areas. (H. REGNES, D.R., 11/13/26) (*U271*)
		(Salmon Mt.)	65	DF	XIII Mt., Thompson Ridge, and the confluence of Stripe and Swet Crs. (R.C. FITZGERALD, D.R., 11/15/26) (*U271*)
	1927	(Paradise)	23,000	GF,ES,DF	In White Cap Cr. and Canyon Cr. drainages, 5% of all GF trees are killed in host stands comprising 70% GF, 15% ES, and 15% DF. An estimated 80% of 1927 growth tips of GF trees are infested compared to 10% on ES trees, and almost none on DF trees. (H. REGNES, D.R., 10/20/27) (*U271*)
	1928	(Paradise)	750	DF	An estimated 70% of all DF trees are infested in 1927 in infested areas in the Little Clearwater R. drainage. (H. REGNES, D.R., 11/13/28) (*U271*)
	1930	(Paradise)	5	ES	In Sec. 19, T.28N., R.14E. (C.K. SPAULDING, D.R., 10/23/30) (*U271*)
	1931	(Paradise)			"*...grosbeaks, flycatchers, and other small birds... increased very materially and seemed to have been instrumental in checking the spruce budworm (in recent years).*" (R. A. PHILLIPS, For. Supv., 11/25/31) (*U271*)
	1934	(Salmon Mt.)	200	DF	In Secs. 26-34, T.28N.,R.14E. "...noticed this condition (defoliation) on trees all over the District, but not in force except as noted." (R.C. FITZGERALD, D.R., 10/31/34) (*U257*)
	1935	(Salmon Mt.)	200	DF	Infestation terminated. (R.C. FITZGERALD, D.R., 12/6/35) (*U257*)
Clearwater (Selway)	1924	Powell (Powell)	32,000	ES,SF	Serious in 1924. (E. MACKAY, D.R., 11/7/25) (*U253,U297*)
	1925	(Powell)	32,000	ES,SF	No spread in 1925. (E. MACKAY, D.R., 11/7/25) (*U253*)
	1926	Lochsa (Lochsa, N3/4)	1,500	ES	Trees of all age classes are attacked throughout the ES type. (R.L. HAND, D.R., 10/21/26) (*U253*)
		(Middle Fk., N1/2)	NR	ES	An estimated 75% of trees of all age classes are attacked throughout the ES type; no tree mortality. (R. FERGUSON, D.R., 11/10/26) (*U253*)
	1927	(Middle Fk., N1/2)	NR	ES,DF,GF	An estimated 75% of the ES trees, 20% of the DF trees, and occasional GF trees above 4,000 feet elevation are attacked throughout the District. (R. FERGUSON, D.R., 11/8/27)(*U253*)
		Pierce (Musselshell)	7,000	DF,ES,GF	New; 3% of host species are attacked. (P.H. GERRARD, Asst. For. Supv., 11/26/27) (*U259*)
(Lolo)	1927	Powell (Elk Summit)	15,000	ES,DF,GF	Scattered throughout Moose Cr. area, increasing. (W.J. BELL, D.R., 11/9/27) (*U270*)
		(Powell)	75,000	SF,ES	Scattered from Papoose Cr. east to Montana border; increasing. (E. MACKAY, D.R., 11/7/27) (*U271*)
(Selway)	1928	Lochsa (Lochsa, N3/4)	11,200*	ES,SF,DF,GF, LPP	Few dead trees were noted. (R.L. HAND, D.R., 10/23/28) (*U253*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Clearwater (Selway)	1928	Lochsa (Middle Fk.,N1/2)	40,000*	DF,GF,ES,SF	General throughout the District above 2,500 feet elevation; heaviest in DF and GF stands above 4,000 feet. About 35% of all SF trees and 25% of all ES trees are infested. Some overmature GF stands contain topkilled trees, presumably from prior infestations. (R. FERGUSON, D.R., 11/9/28)(*U253*)
(Selway)	1928	Pierce (Mussel-shell)	6,600	GF	Forks of Lolo Cr. and on French Mt.; sawlog size trees. (J.E. KAUFFMAN, D.R., 10/30/28) (*U259*)
(Lolo)	1928	Powell (Elk Summit)	15,000	ES,GF,DF	In the Moose Cr. drainage. (L.D. ROBINSON, D.R., 11/21/28) ([illegible])
		(Powell)	30,000	SF,ES	Static in the Squaw Cr. and Papoose Cr. areas. (E. MACKAY, D.R., 11/12/28) (*U270*)
Clearwater	1929	Canyon	80	DF,GF	Active in the Beaver Cr. drainage during the past years. (O.A. KNAPP, D.R., 11/20/29) (J.E. KAUFMANN, D.R., Chamberlain R.D., 10/28/30) (*U259*)
Clearwater (Selway)	1929	Lochsa (Lochsa, N3/4)	9,400*	ES,SF,DF,GF, LPP	No change over 1928; *infested acreage was reduced from forest fires this year.* (R.L. HAND, D.R., 11/7/29) (*U253*)
		(Middle Fk.,N1/2)	39,000*	GF,DF,ES	No change over 1928. (R. FERGUSON, D.R., 11/11/29) (*U253*)
(Lolo)	1929	Powell (Elk Summit)	15,000	GF,DF,ES	In the Moose Cr. area; decreasing. (F. OTTER, D.R., 11/11/29) (*U270*)
		(Powell)	17,000	ES,GF	In the Squaw Cr. and Papoose Cr. areas; very light. (E. MACKAY, D.R., 11/12/29) (*U270*)
Clearwater (Selway)	1930	Lochsa (Lochsa, N3/4)	22,500*	ES,GF	All trees are infested in the ES and GF types from 4,000 to 6,000 feet elevation. (F. W. SHANER, D.R., 9/25/30) (*U253*)
		(Middle Fk.,N1/2)	39,000*	GF,DF,ES	Generally lighter; *defoliation may be masked by damage from numerous hailstorms.* More dead trees appearing. (R. FERGUSO D.R., 11/8/30) (*U253*)
Clearwater	1930	Pierce (Mussel-shell)	NR	GF,DF,ES	Decreasing. (R. JOHANSON, D.R., Musselshell, R.D., 11/3/30) (*U259*)
Clearwater (Selway)	1931	Lochsa (Middle Fk., N1/2)	20,000*	DF,GF,ES,SF	Decreased throughout. (R. FERGUSON, D.R., 11/2/31) (*U253*)
Clearwater	1932	Bungalow	1,500	DF,GF	In the Elk Mt. area; trees 50 to 60 years old are infested. (W.L. CLOVER, D.R., Oxford R.D., 9/5/32) (*U259*)
Clearwater (Selway)	1932	Lochsa (Middle Fk., N1/2)	10,000*	DF,GF	Decreased, attacks lighter; dead limbs beginning to appear from defoliation in the previous years. (R. FERGUSON, D.R., 11/10/32) (*U253*)
		(Selway, N1/4)	15,000*	ES,GF	Light in host stands between 4,000 and 6,000 feet elevation. (F.W. SHANER, D.R., 11/4/32) (*U253*)
Clearwater	1933	Bungalow	1,500	DF,GF	Elk Mt. area; all-aged host trees infested. (F. MENEALY, D.R., Oxford R.D., 8/28/33) (*U259*)
Clearwater (Selway)	1933	Lochsa (Middle Fk.,N1/2)	32,000*	GF,DF	Very light. (R. FERGUSON, D.R., 11/15/33) (*U253*)
		(Selway, N1/4)	NR	ES,GF	NR in 1933; referred to in 1934 report. (F.W. SHANER, D.R., 11/21/34) (*U253*)

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ble 4. (con.)

tional rest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
earwater elway)	1934	Lochsa (Selway, N1/4)	3,500	ES,GF	Increased over that in 1933; *considerable infested forest was burned this year.* (F.W. SHANER, D.R., 11/21/34) (*U253*)
olo)	1946	Powell (Powell)	100,000	ES,GF	Very heavy in the Papoose Cr. drainage. (H.J. VICHE, D.R., 11/20/46) (*U270*)
	1947	(Powell)	100,000	ES,GF,SF	Decreased in the Lochsa R. drainage. (H.A. STREED, D.R., 12/3/47) (*U270*)
	1948	(Powell)	100,000	SF,ES,DF,GF	Scarcely evident in the Lochsa R. drainage. (W.R. MOORE, D.R., 11/5/48) (*U270*)
olo)	1949	Powell (Powell)	25,000*	DF,ES,SF,GF	New but declining in the Beaver Cr., Storm Cr., and White Sand Cr. drainages and on Dan and Savage Ridges. (W.R. MOORE, D.R., 10/24/49) (*U270*)
	1950	(Powell)	NR	DF,ES,SF,GF	Declined. Defoliation was heavy from budworm feeding in 1949 in the White Sand Cr. and Storm Cr. areas. (W.R. MOORE, D.R., 11/13/50) (*U270*)
	1950	(Powell)	10,600	DF,GF,SF	(R.E. DENTON, Entomol., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, Feb. 1952 and 7/29/50) (*U41*)
	1951	(Powell)	NR	DF,ES,SF,GF	Mostly declined throughout the District; some new infestations in the Storm Cr. and Haskell Cr. drainages. (W.R. MOORE, D.R., 10/3/51) (*U271*)
			23,700	DF,GF,SF	Defoliation was heavy on 5,000 acres of new infestation south of Lolo Divide. No tree mortality has been observed to date in any infested area, but some topkilling of trees is evident. (R.E. DENTON, Entomol., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, Feb. 1952) (*U44*)
earwater olo)	1952	(Powell)	80,400	SF,DF,ES	Heavy defoliation was seen only on 5,400 acres in the Cabin Cr. and Haskell Cr. areas. *Defoliation throughout infested areas is heaviest in SF trees, least in ES trees.* (R.E. DENTON, Entomol., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, 11/6/52) (*U45*)
	1953	(Powell)	NR	SF	Extensive feeding noted, mostly on SF understory trees in the Storm Cr., Brushy Cr., and Haskell Cr. areas. Aerial spraying is planned for these areas in 1954. (W.R. MOORE, D.R., 9/23/53) (*U270*)
eur Alene	1924	Kingston	NR	DF,GF	Covered a considerable area in the Steamboat Cr. and Cougar Cr. areas; in "minor (host) species." Apparently continuing from preceding years. A smaller area in the N.Fk. Coeur d'Alene R. drainage, of more recent origin. (W.W. WHITE, Forester, For. Serv., North. Reg., Missoula, Mont., 1/9/25) (*U297*)
	1928	Kingston (Lower N. Fk.)	16,800	GF	In the Steamboat, Cougar, and Grizzly Cr. drainages. (C.B. HAND, D.R., 11/3/28) (*U260*)
	1929	Kingston-Fernan (Little River)	30,000	GF,DF,ES,WWP	Attacks were severe in the Laverne Cr. and Lieberg Cr. areas. (G.S. HAYNES, D.R., 11/13/30) (*U260*)
		Magee	NR	GF,DF,WH,ES	Tepee Summit, NW 1/4, Sec. 23, T.51N., R.1E.; heaviest in the GF type. (J.C. EVENDEN, Entomol., Bur. Entomol., Coeur d'Alene, Idaho, 10/1/29) (Unpubl. field notes filed at For. Sci. Lab., For. Serv., Moscow, Idaho)
	1930	Kingston-Fernan (Little River)	30,000	GF,DF,ES	Decreased in the Laverne Cr. and Lieberg Cr. areas. (G.S. HAYNES, D.R., 11/13/30) (*U260*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Coeur d'Alene	1931	Kingston (Little River)	30,000	GF,DF,ES	Heavy in the Cougar Cr. drainage. (G.S. HAYNES, D.R., 11/23/32) (*U260*)
	1932	(Little River)	30,000	GF,DF,ES	Static. (G.S. HAYNES, D.R., 11/23/32) (*U260*)
	1933	Kingston-Fernan (Little River)	20,000	GF,DF,ES,WWP	In the Laverne Cr. and Lieberg Cr. areas. (G.S. HAYNES, D.R., 11/15/33) (*U260*)
	1941	Wallace	NR	SF	In the head of Cottonwood Cr., T.50N.,R.5E. (C.H. SCRIBNER D.R., Trout Cr. R.D., Cabinet N.F., Idaho, 11/21/41) (*U258*)
Kaniksu	1922	Priest Lake (Bismark)	NR	WH	A report was made of WH trees killed by undetermined insects at Priest Lake, Idaho. (J. A. FITZWATER, For. Supv., Newport Wash., Jan. 1922) (*35,36,37,U60*)
	1922	Priest Lake (Bismark)	NR*	WH,WWP,GF,WL, ES,WR	Feeding larvae were collected from named hosts from parts of Secs. 1-2, T.60N., R.5W.; Sec. 6, T.60N.,R.4W.; Secs. 23-26, 35-36, T.61N.,R.5W.; and Secs. 19,30-31, T.61N., R.4W. between Kalispell Cr. and Reeder Cr. (H.J. RUST, Entomol., Ranger, Bur. Entomol., Coeur d'Alene, Idaho Original field notes and map, 6/27/22). *Subsequent determination of reared adults as* Harmologa fumiferana *(Clemens) by C. HEINRICH, Insect Taxonomist, Washington, D.C., makes this the first spruce budworm infestation of record in the western United States. (35,36,37,U60)*
	1923	Priest Lake (Bismark)	NR	WH,WWP,GF	In the Kalispell Cr. area, mostly noted in WH reproduction, saplings, and poles in cutover areas. Some WWP and GF reproduction was infested. Defoliation was less than in 1922. (H.J. RUST, Entomol. Ranger, Bur. Entomol., Coeur d'Alene, Idaho. Original field notes, 7/16/23)
	1924	Priest Lake (Bismark)	NR	WH,WWP,ES,GF	Continued in the Kalispell Cr. timber sale area; younger trees are the most defoliated. Proposed control of budworm in connection with eradication of WH on sale area is questioned. (W.W. WHITE, Forester, For. Serv., Northern Reg., Missoula, Mont., 1/9/25) (*U297*)
Kaniksu (Cabinet)	1941	Trout Creek (Trout Creek)	300	SF	In the head of the E.Fk. Trout Cr. drainage. The insect responsible was not identified, inasmuch as collected specimens were lost, but from the District Ranger's description of the larvae, moths, and host tree damage, the budworm was suspect. (C.H. SCRIBNER, D.R., 11/21/41) (*U258*)
Nezperce	1924		NR	NR	"The spruce budworm is found in large numbers all over the Forest. Just how serious the loss from the epidemic is cannot yet be predicted." (W.W. WHITE, Forester, For. Serv. Northern Reg., Missoula, Mont., 1/9/25) (*U297*)
		Red River	55,700	DF	In the Bargamin, Otterson, Lower Big Mallard Crs. drainages. From 10% to 20% of the host stands are infested in these drainages. (E. McCONNELL, D.R., 11/2/25) (*U271*)
	1925	Clearwater	600	GF,DF,ES	Declined on Grouse Cr. Ridge; light attacks noted elsewhere in the District. (V. L. COLLINS, D.R., 11/14/25) (*U271*)
		Red River	55,700	DF	No change in the infestation over that in 1924. (E. McCONNELL, D.R., 11/2/25) (*U271*)

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le 4. (con.)

ional est	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
perce	1926	Clearwater	NR	GF,DF,ES LPP,WL	Occasional trees were defoliated throughout District (V.L. COLLINS, D.R., 11/16/26) (*U271*). Attacks were heaviest on GF trees, thence on DF trees, and least on trees of other hosts. (L.C. HURTT, For. Supv., 11/16/26) (*U271*)
		Elk City	1,000	GF,DF	In the vicinity of Orogrande. (D.R., unidentified, 11/2/26) (*U271*)
			7,000	GF,DF	East Newsome Cr. basin; new infestation. (C.D. BLAKE, Asst. For. Supv., 11/22/26) (*U271*)
perce lway)	1926	Moose Creek (Moose Cr., all)	3,000	GF,ES,DF,PP	First year; throughout the eastern part of the District. (F.W. SHANER, D.R., 11/1/26) (*U253*)
		(Bear Cr., N1/2)	NR	ES,SF	General throughout the ES-SF type. (J.A. PARSELL, D.R., 11/29/26) (*U253*)
		(Lochsa, S1/4)	500	ES	Increased in high-elevation ES stands. (R.L. HAND, D.R., 10/21/26) (*U253*)
	1926	Red River	55,700	DF,GF	Same as in 1925. E. McCONNELL, D.R., 11/11/26) (*U271*)
		Selway (Selway, all)	120	ES	On Iron Mt.; increased rapidly. (C.S. CROCKER, D.R., 11/7/26) (*U253*)
		(Middle Fk., S1/2)	NR	ES	Most all ES stands on the District are infested. Increased. No tree mortality was noted. (R. FERGUSON, D.R., 11/10/26) (*U253*)
perce	1926	Slate Creek	NR	GF,DF,WL	Increased. (Reported tree mortality was later disputed by the Forest Supervisor.--Authors.) (H.W. HIGGINS, D.R., 11/5/26) (*U271*)
	1927	Clearwater	NR*	GF,DF,ES,SF, LPP, WL	Most host stands were infested throughout District; heaviest in the DF-GF type, least in the DF-PP type. (V.L. COLLINS, D.R., 11/15/27) (*U271*)
	1927	Elk City	NR*	ES,GF,DF,SF	All firs were infested throughout District. (D.R., unidentified, 11/2/27) (*U271*)
perce lway)	1927	Moose Creek (Bear Cr., N1/2)	250*	DF,GF,ES	Increased in the Crow Cr., Cub Cr., and Brush Fork Cr. areas. (L.W. LEWIS, D.R., 11/19/27) (*U253*)
		(Lochsa, S1/4)	2,000*	ES,SF,LPP	Increased in the ES type throughout the District; no tree mortality seen. (R.L. HAND, D.R., 10/17/27) (*U253*)
		(Moose Cr., all)	NR*	GF,ES,DF	Most host stands were infested throughout District; increased in severity. Dead GF trees were observed in the Indian (Pettibone) Cr. area. (F.W. SHANER, D.R.,10/18/27) (*U253*)
perce	1927	Red River	53,800*	DF,GF	In the Bargamin Cr., Moose Cr., Otterson Cr., and lower Big Mallard Cr. drainages. (EARL McCONNELL, D.R., 11/3/27). Attacks in Bargamin Cr. appeared greater than indicated. (C.D. BLAKE, Acting For. Supv.) (*U271*)
perce lway)	1927	Selway (Meadow Cr., all)	NR	GF	Increased in GF stands throughout the District; defoliation was not severe. (A.C. CAMPBELL, D.R., 11/21/27) (*U253*)
		(Middle Fk., S1/2)	NR	ES,DF,GF	Host stands above 4,000 feet elevation were infested throughout the District; about 75% of the ES trees, 20% of the DF trees, and an occasional GF tree were infested. (R. FERGUSON, D.R., 11/8/27) (*U253*)
		(Selway, all)	50,000	ES	All ES stands were infested in the Iron Mt.-Beargrass Pt. area; increased. (C.S. CROCKER, D.R., 10/24/27) (*U253*)
perce	1927	Slate Creek	96,000*	GF,DF,ES,WL, LPP	New this year; increased in all host types between 2,000 and 6,500 feet elevation. Defoliation was heaviest on DF, GF, and ES trees, sparse and only occasional on WL and LPP trees. (O.V. CLOVER, D.R., 12/8/27) (*U271*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Nezperce	1928	Clearwater	NR	GF,SF,DF,ES, LPP, WL	Same areas were infested as in 1927; defoliation was less than in 1926 or 1927. (V.L. COLLINS, D.R.,11/16/28) (*U271*)
		Elk City	NR	DF,GF,ES	Same areas were infested as in 1927, but there was about 50% less defoliation. (G.C. SPACE, D.R.,11/15/28)(*U271*)
Nezperce (Selway)	1928	Moose Cr. (Bear Cr., N1/2)	600*	GF,DF	Increased in the Crow Cr. and S.Fk. Running Cr. drainages. (L.W. LEWIS, D.R., 11/1/28) (*U253*)
		(Lochsa, S1/4)	2,800	ES,SF,GF,DF, LPP	Static in the Lake Cr., Lost Cr., and Indian Grave Cr. drainages. (R.L. HAND, D.R., 10/23/28) (*U253*)
		(Moose Cr., all)	40,000*	ES,GF	Increased in severity throughout the District; trees were beginning to die in older infested areas. (F.W. SHANER, D.R., 10/26/28) (*U253*)
Nezperce	1928	Red River	53,800	DF,GF	Same areas were infested as in 1927; defoliation was less severe. (E. McCONNELL, D.R., 11/13/28) (*U271*)
Nezperce (Selway)	1928	Selway (Meadow Cr., all)	90,000*	GF,DF,ES,LPP	Increased in severity throughout the District, particularly in GF stands. (A.C. CAMPBELL, D.R., 11/8/28) (*U253*)
		(Middle Fk.,S1/2)	40,000*	DF,GF,ES,SF	Most host stands were infested throughout the District; infestation increased in severity, particularly in mature stands. (R. FERGUSON, D.R., 11/9/28) (*U253*)
		(Selway, all)	50,000*	ES,GF	Heavy defoliation, becoming greater, was evident in all ES-GF stands above 5,000 feet elevation in the Iron Mt.-Beargrass Pt. area. No tree mortality was seen. (C.S. CROCKER, D.R., 10/29/28) (*U253*)
Nezperce	1928	Slate Creek	164,000	GF,DF	Decreased defoliation, scarcely detectable. (O.V. CLOVER, D.R., 11/22/28) (*U271*)
	1929	Clearwater	NR	GF,SF,DF,ES, LPP, WL	Same areas were infested as in 1927 and 1928. New foliage growth was almost completed before defoliation from larval feeding was detectable. (V.L. COLLINS, D.R., 11/15/29)(*U271*
		Elk City	NR	DF,GF,ES	Decreased in severity throughout District. (GEORGE R. SPACE, D.R., 11/6/29) (*U271*)
Nezperce (Selway)	1929	Moose Cr. (Bear Cr., N1/2)	5,000	GF,DF	Same as in 1928; increased. (L.W. LEWIS, D.R., 10/14/29) (*U253*)
		(Lochsa, S1/4)	2,100	ES,SF,GF,DF	Static. (R.L. HAND, D.R., 11/7/29) (*U253*)
		(Moose Cr., all)	40,000	ES,GF	Same areas were infested as in 1928; increased in severity. (F.W. SHANER, D.R., 10/26/29) (*U253*)
Nezperce	1929	Red River	53,800	DF,GF	Declined in severity in 1928-infested areas. (E. McCONNELL D.R., 11/1/29) (*U271*)
Nezperce (Selway)	1929	Selway (Meadow Cr., all)	26,600*	GF,DF,ES	Declined in severity in 1928-infested areas; GF trees were the most severely defoliated of the principal host trees. (A. C. CAMPBELL, D.R., 11/8/29) (*U253*)
		(Middle Fk.,S1/2)	39,000*	GF,DF,ES	Static; some patches of host reproduction were killed. (R. FERGUSON, D.R., 11/11/29) (*U253*)
		(Selway, all)	31,000*	GF,ES	Observed throughout the southern part of the District; infested areas diminished, *but defoliation of GF trees was greater than in 1928. Top-killing of trees common in ES and GF stands,* but no tree mortality evident. *Seed crops have been very light in stands infested during past 3 years; the District Ranger questioned whether budworm was responsible.* (C. S. Crocker, D. R., 10/24/29) (*U253*)

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ıble 4. (con.)

ational Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
ezperce	1930	Clearwater	NR	GF	Increased to previous levels of severe defoliation in all GF stands throughout the entire District between 4,000 and 6,000 feet elevation. (V.L. COLLINS, D.R., 11/19/30)(*U271*)
ezperce (Selway)	1930	Moose Creek (Bear Cr., N1/2)	NR*	ES,GF,DF	(L.W. LEWIS, D.R., 10/18/30) (*U253*)
		(Lochsa, S1/4)	1,000*	ES,GF	In the Lochsa R. drainage; static. (F.W. SHANER, D.R., 9/25/30) (*U253*)
		(Moose Cr., all)	41,200*	SF,ES	In the Three Link Cr., Martin Cr., Big Cr., and Indian Cr. drainages; static. (G.W. CASE, D.R., 11/3/30) (*U253*)
ezperce	1930	Red River	63,000*	DF,GF	Severity of infestation diminished to pre-1927 level; 20% of the host timber in Bargamin Cr. and Otterson Cr., 10% in Big Mallard Cr. and Moose Cr., and 2% in the Meadow Cr. drainage was infested. (E.McCONNELL, D.R., 11/10/30)(*U271*)
ezperce (Selway)	1930	Selway (Meadow Cr., all)	600*	GF,DF	On Green Ridge, Indian Hill Ridge, and on the north slopes of the Selway R. drainage; decreased (apparently new or previously unreported infestations.--Authors.) (A.C. CAMPBELL, D.R., 10/19/30) (*U253*)
		(Middle Fk., S1/2)	39,000*	GF,DF,ES	No spread; decreased defoliation. Tree mortality began to appear in second-growth host stands continuously infested during the past 3 years. (R. FERGUSON, D.R, 11/9/30) (*U253*)
		(Selway, all)	50,000*	GF,ES	Same as in 1929, did not spread. Defoliation was heavy on 20,000 acres, lighter on 30,000 acres. No tree mortality seen. *Very poor seed crops were evident in infested stands.* (C.S. CROCKER, D.R., undated) (*U253*)
zperce	1931	Clearwater	NR	GF,DF,ES,SF, LPP, WL	Most of the fir types on the District were infested, but 1931 foliage was only partially destroyed. Top-killing of host trees was very prevalent from the cumulative defoliation of past few years. (V.L. COLLINS, D.R., 11/18/31)(*U271*)
zperce (Selway)	1931	Moose Creek (Bear Cr., N1/2)	1,800*	GF,DF	In the Mink Cr., Martin Cr., and Brushy Fork Cr. drainages; decreased in severity. (L.W. LEWIS, D.R., 11/17/31) (*U253*)
		(Lochsa, S1/4)	NR*	NR	NR
		(Moose Cr., all)	NR*	NR	NR
		Selway (Meadow Cr., all)	500*	GF,DF	Groups of infested host trees were scattered on Green Ridge and along the north slopes of the Selway R. drainage; many trees have died from attacks in 1930. Decreased infestation. (A.C. CAMPBELL, D.R., 10/27/31) (*U253*)
		(Middle Fk., S1/2)	NR*	DF,GF,ES,SF	Infestations that increased from 1927 to 1929 decreased in 1930 and 1931. Defoliation was still heavy in 1931 in the vicinity of Corral Hill and Frenchman Butte. (R. FERGUSON, D.R., 11/2/31) (*U253*)
		Selway (Selway, all)	50,000*	GF,ES	Less severe than in 1928-1930. (C.S. CROCKER, D.R., 9/22/31) (*U253*)
ezperce	1932	Clearwater	NR	GF,SF	Light in all fir types throughout the District; infestations have been continuous since 1923. (V.L. COLLINS, D.R., 11/2/32) (*U271*)
ezperce (Selway)	1932	Moose Cr. (Moose Cr., all)	NR*	SF,ES	Very light in host types at higher elevations throughout the District; decreased. (G.W. CASE, D.R., 11/5/32)(*U253*)
		Selway (Meadow Cr., all)	500*	GF	Decreased. Abundant top killing and mortality of host trees resulted from the infestations of 1932 and previous years. (A.C. CAMPBELL, D.R., 9/28/32) (*U253*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Nezperce (Selway)	1932	(Middle Fk., S1/2)	160,000*	DF,GF	Declining. (R. FERGUSON, D.R., 11/10/32) (*U253*)
		(Selway, all)	60,000*	ES,GF	Decreased. (Acreage of mapped infestations appears smaller than reported.--Authors). (F.W. SHANER, D.R., 11/4/32)(*U253*)
Nezperce	1933	Clearwater	NR	GF,SF	Extent as the same as that in 1932, but with decreased hos damage. (V.L. COLLINS, D.R., 11/16/33) (*U271*)
Nezperce (Selway)	1933	Moose Cr. (Moose Cr., all)	40,000*	ES,SF,GF	Increased in the Indian Cr., Battle Cr., Moose Cr., Squaw Cr., Bear Cr., and Martin Cr. drainages; occasional pole-size host trees were killed. (G.W. CASE, D.R., 11/28/33) ([illegible])
		Selway (Middle Fk., S1/2)	NR*	GF,DF	General throughout the District since 1927, heaviest at first in host stands from 5,000 to 6,000 feet in elevation. Infestations were most active during 1928 and 1929 when ver heavy host tree damage was noted. Generally declining infestations during 1930 and 1931 but with scattered pocket of heavy host tree damage. Further declining infestations in 1932 and 1933 centered in overmature GF stands in the Clear Cr., Goddard Cr., and Hamby Cr. drainages. The accompanying map identifies one area very heavily infested from 1928 to 1932 in which about 75% of the host trees were dead; other areas shown to be still heavily infested contained stands in which about 10% of the host trees were dead and about 15% of the remainder were topkilled. Nearly all the latter stands comprised overmature, long-decadent GF trees. (R. FERGUSON, D.R., 11/15/33) (*U253*)
		(Selway, all)	NR*	ES,GF	Many host stands in the western part of the District showed an increasing incidence of attacks and of tree mortality. (F.W. SHANER, D.R., 10/29/33) (*U253*)
	1934	Moose Cr. (Moose Cr., all)	20	ES,SF	Drastically decreased. Infested host trees average 18 inches d.b.h. (G.W. CASE, 10/24/34) (*U253*)
		Selway (Middle Fk., S1/2)	NR	GF,DF	Apparently terminated. In some areas infested since 1927, 70% of the trees were dead in patches of host type covering up to 20 or 30 acres, although the overall cumulative tree mortality Districtwide was only about 2%. Many host trees adjudged to be dead or dying in previous years are apparently surviving. (C.A. MacGREGOR, D.R., 11/27/34) (*U253*)
		(Selway, all)	14,000	ES,GF	Slight increase. About two of every three trees in the hos types were infested. *Much budworm-infested timber was burned this year.* (F.W. SHANER, D.R., 11/21/34) (*U253*)
Nezperce	1935	Clearwater	NR	GF,SF	Diminished. Although most of the GF foliage throughout the District has been fed upon heavily since 1924, almost none was eaten in 1935. (V.L. COLLINS, D.R.,11/15/35) (*U27*)
		Selway (Middle Fk., S1/2)	150	DF	Dying out, but defoliation was noted this year in the S.Fk Canyon Cr. area. It was estimated that budworm defoliatio since 1928 had killed 10% of the GF and SF trees above 3,0 feet elevation, and that 50% of these tree species had bee killed in the head of the Goddard Cr., Hamby Cr., and Clea Cr. drainages. (C.A. MacGREGOR, D.R., 11/15/35) (*U271*)
		Selway	60,000*	ES,GF	Static in the south side of the Selway R. from O'Hara to Meadow Crs., except for spot increases. Approximately 60% of the ES and GF types were infested; in these, about 20% of the trees appeared to have died from cumulative defolia tions. (C.D. SOUSLEY, D.R., 11/7/35) (*U271*)
	1936	Selway	60,000	GF,ES	Spots of light infestation were detected throughout the District. (C.D. SOUSLEY, D.R., 11/11/36) (*U271*)

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able 4. (con.)

ational orest	Year	Ranger district	Infested acre	Host tree species	Pertinent infestation conditions, reporter, and references
ezperce	1937	Clearwater	NR	GF,SF	Less than 1% of the host trees in the District were infested. (B.A. GOODMAN, D.R., 11/24/37) (*U271*)
		Selway	60,000	GF,ES	Static; mostly restricted to GF stands. (C.D. SOUSLEY, D.R., 11/5/37) (*U271*)
	1938	Clearwater	NR	GF,SF	Static. (B.A. GOODMAN, D.R., 11/9/38) (*U271*)
	1939	Clearwater	NR	GF,SF	Static; same as in 1937 and 1938. (B.A. GOODMAN, D.R., 11/13/39) (*U271*)
	1940	Clearwater	NR	GF,SF	Declined in severity; larger host trees only were infested at higher elevations. (C.S. WALKER, D.R., 11/13/40) (*U271*)
	1941	Clearwater	NR	GF	Infested trees up to 12 inches d.b.h. occurred singly, no more than four or five per section throughout the District. (C. S. WALKER, D.R., 11/3/41) (*U271*)
	1942	Clearwater	NR	GF	Same as in 1941. (R. L. SPACE, D.R., 11/19/42) (*U271*)
	1943	Clearwater	NR	GF	Same as in 1941. (R. L. SPACE, D.R., 12/2/43) (*U271*)
	1945	Salmon R.	NR	DF	In the Kessler Cr. drainage. (R.B. JORGENSEN, D.R., 11/10/47) (*U271*)
	1946	Salmon R.	NR	DF	Same as in 1945. (R.B. JORGENSEN, D.R., 11/10/47)(*U271*)
	1947	Salmon R.	NR	DF	Increased at scattered locations throughout the District. Trees infested in Kessler Cr. in 1945 and 1946 were now dead. (R.B. JORGENSEN, D.R., 11/10/47) (*U271*)
	1948	Salmon R.	NR	DF (mostly), GF	1947-reported infestations increased in severity. (R.B. JORGENSEN, 11/12/48) (*U271*)
	1949	Salmon R.	NR	DF,GF	Increased. Light to heavy defoliation throughout the District, heaviest in the Sherwin Cr., Cow Cr., Bean Cr., W.Fk. Race Cr., and W.Fk. Rapid R. drainages. (R.B. JORGENSEN, D.R., 11/14/49) (*U271*)
	1950	Salmon R.	NR	DF,GF	Same as in 1949. Host tree mortality increased from cumulative defoliation of past several years. (R.B. JORGENSEN, D.R., 11/7/50) (*U271*)
	1951	Salmon R.	NR	DF,GF,ES	Increased throughout the District. Defoliation was heaviest in previously infested host stands in the Sherwin Cr., Cow Cr., Bean Cr., W.Fk. Race Cr., and W.Fk. Rapid R. drainages; also heavy in first-year infestations in the Oxbow Cr., Wygant Cr., Papoose Cr., and W.Fk. Rapid R. drainages and on Whitebird Ridge. (R.B. JORGENSEN, D.R., 10/8/51) (*U271*)
	1953	Salmon R.	NR	DF,GF,ES	Defoliation was general over the District. Approximately 16,070 acres of infested host type in the Papoose Cr. and Bean Cr. drainages were aerially sprayed in July with DDT. (J.R. ALLEY, D.R., 11/24/53) (*U271*)
:. Joe	1927	Avery (Roundtop)	160*	ES	In Sec. 12, T.43N.,R.5E., Twin Cr. Administrative Site (now Twin Cr. Campground). Increased in 0- to 80-year-old ES stands. (H.L. FLODBERG, D.R., 11/8/27) (*U272*)
	1928	Avery	NR	ES	Confined to scattered host trees. Not serious. (L.M. DUNN, D.R., 10/29/28) (*U272*)
	1928	Palouse	30*	WL	In Secs. 1-2, T.42N.,R.3E., on the ridge between Mannering and E.Fk. Meadow Crs. (near Giant White Pine Tree). Scattered patches of 1 to 3 acres of 30-year-old host trees (5 inches and smaller) were infested. First season attacks were observed. (W.H. DAUGS, D.R., 11/14/28) (*U272*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
					MONTANA
Beaverhead (Madison)	1925	Sheridan (Ruby, all)	6*	DF	In S1/2 Sec. 4, T.9S.,R.3W. Static. (B.P. MARTIN, D.R., 11/14/25) (*U250*)
Beaverhead		Wisdom	0.5	ES	In T.1N. and T.1S.,R.17W., upper Johnson Cr. drainage. Slowly increased. (M.G. RAMSEY, D.R., 11/1/25) (*U256*)
Beaverhead (Madison)	1926	Sheridan (Ruby, all)	6	DF	Same area as in 1925, but with decreasing defoliation. (B.P. MARTIN, D.R., 11/14/26) (*U250*)
	1927	Madison (Lyon)	800	ES	In Secs. 10,11,14,15; T.12S.;R.2W.; Cascade Cr. drainage. Increased defoliation. (C.A. JOY, D.R., 11/9/27) (*U250*)
	1928	(Lyon)	800	ES	Same areas as in 1927; static. (C.A. JOY, D.R.,11/14/28) (*U250*)
	1929	(Lyon)	800	ES	Same areas as in 1928; static. (C.A. JOY, D.R., 11/15/29) (*U250*)
Beaverhead	1931	Sheridan	NR	ES,DF	Stonewall and other areas in the Tobacco Root Mts. and in the upper Ruby R. drainage. New. Young age classes of host trees were infested. (H.E. SCHWAN, D.R., 11/23/31) (*U256*)
	1941	Madison	NR	ES	Most all ES seedlings and saplings in the District were infested to some degree. Tree mortality was rare. (E.W. STEIN, D.R., 11/21/41) (*U256*)
	1949	Lima	NR	DF(?)	Scattered in open-type host stands throughout the District. (E.E. REDMAN, For. Supv., 11/29/49) (*U256*)
	1951	Wisdom	NR	ES,SF	Endemic throughout the District. (E.E. REDMAN, For. Supv., 10/12/51) (*U256*)
	1953	Madison (Ennis)	NR	DF	Moderate to severe defoliation was noted on 690 acres in the Meadow Cr. drainage; light defoliation was evident in all other DF stands throughout the District. Damage increased in the Tobacco Root Mts. (W.H. MacKENZIE, D.R., 10/13/53) (*U256*)
		Madison	20,000	DF	Defoliation increased generally, but decreased in severity from north to south in an area comprising the Wigwam Cr., Morgan Cr., Cherry Cr., Ruby Cr., Wall Cr., and Johnny Gul. drainages. Light defoliation from budworm feeding was seen in these areas in the past few years, but no host tree mortality has resulted. Privately-owned DF stands south of Virginia City were also infested in 1953. (R.R. SCHULZ, D.R., 9/15/53) (*U256*)
Bitterroot	1927	Stevensville (North End)	800*	ES,GF	In the Big Cr. drainage. Increased damage; only young trees were infested. (T.J. DONICA, D.R., 11/28/27)(*U257*)
	1938	Stevensville	1,000	ES	In the Upper Burnt Fork Bitterroot R., in T.7N.,R.18W. Widespread, including ornamental trees in the (Bitterroot) Valley. (O.E. YORK, D.R., 12/2/38) (*U257*)
		West Fork	1,000	DF	Unknown insect caused defoliation of current season's needle needles often were not completely consumed; some trees were killed (presumably budworm.--Authors). (S.H. LARSON, D.R., 11/12/38) (*U257*)
	1951	Sula	NR	DF	Heavy. Adventitious growth on host trees indicated prior infestations of several years' duration. (S.T. BILLINGS, D.R., West Fork R.D., Oct. 1951) (*U257*)
		West Fork	4,500	DF	Very severe and spreading. South side of Deer Cr. presumab infested for several years, as indicated by adventitious growth of host trees. Large groups of DF trees were attack

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Bitterroot	1951	West Fork (con.)			by the Douglas-fir beetle in this area. New infestations of budworm were observed in 1951 on the north side of Deer Cr. and in the Thunder Mt., Alta, and Woods Cr. areas. (S.T. BILLINGS, D.R., Oct. 1951) (*U257*)
	1953	Sula	NR	DF,ES,GF,SF	Very light to heavy throughout the District. The 12,000 acres of infested timber type aerially sprayed with DDT during July 9 and 10, 1952 (Guide Cr., Jennings Camp Cr., and E.Fk. Bitterroot R.) were reinfested this year. (V.O. HAMRE, D.R., 9/18/53) (*U257*)
		West Fork	NR	DF	Decreased; almost all DF type was infested in the Overwhich Cr. area. Spread this year to Taylor Cr. and along the west side of the W.Fk. Bitterroot R. to Coal Cr. (S.T. BILLINGS, D.R., 11/18/53) (*U257*)
Custer	1935	Beartooth (Stillwater)	NR	ES	Very light; static. Only scattered trees in the Stillwater R. and W.Fk. Rosebud Cr. drainages were infested. (R.F. COONEY, D.R., 7/17/35) (*U262*)
	1937	Beartooth (Stillwater)	NR	ES	Same conditions as in 1935, but in T.6S.,R.14-15E. in the Stillwater R. drainage. No tree mortality was observed. (C.S. WALKER, D.R., 11/8/37) (*U262*)
	1939	Beartooth (Stillwater)	NR	ES	Endemic; in the Stillwater R. drainage (T.6-7S.,R.14E.) R.G. GALLUP, D.R., 11/21/39) (*U262*)
	1940	Beartooth (Stillwater)	40	ES	Static in the area reported on in 1939. (R.G. GALLUP, D.R., 11/6/40) (*U262*)
Deerlodge	1945	Boulder	480	DF	In the N.Fk. Little Boulder R. drainage in T.5N.,R.5W. (W.K. BRAY, Acting D.R., 11/19/45) (*U263*)
		Whitehall	NR	DF	In Bigfoot Park, Secs. 6-7, 18-19; T.4N.,R.4W.; Secs. 1-2, 11-14, 23-24; T.4N.; R.5W. Widespread. Some tip and branch killing was seen on occasional trees, but no host tree killing. (R. E. DICKINSON, D.R., 11/16/45) (*U263*)
	1946	Boulder	NR	DF	In the Elkhorn Unit, Little Boulder R., N.Fk. Boulder R., Galena Gul., and Hadley Park areas in T.5-6N.,R.2-4W. Light throughout but with increased defoliation and spread westward. (A.J. ARTHURS, D.R., 11/4/46) (*U263*)
		Whitehall	NR	DF	In the Bigfoot Park, Pony Canyon, Whitetail Cr., Bull Mts., and Hells Canyon areas. Increased and spread southwestward. (R.E. DICKINSON, D.R., 9/10/46) (*U263*)
	1947	Whitehall	NR	DF,ES	Light throughout most of the District, but severe in the State Cr., Beaver Cr., and Hay Canyon areas where up to 50% of the host trees in patches up to 200 acres in size were completely defoliated but alive. (G.F. ROSKIE, D.R., 11/20/47) (*U263*)
	1948	Boulder	NR	DF	All of the Elkhorn Unit and Little Boulder R. drainage were infested. Did not spread. Moth populations were markedly smaller. (R.E. LOCKHART, D.R., 11/3/48) (*U263*)
		Whitehall	NR	ES	Endemic in the S. Boulder R. drainage of the Tobacco Root Mts. and in Hells Canyon. Defoliation was light. (C.L. HAGEDORN, Asst. D.R., 11/10/48) (*U263*)
	1949	Boulder	NR	DF	In the Elkhorn Cr., Dry Cr., Muskrat Cr., and Little Boulder R. drainages in T.5N., R.4-5W., T.6N., R.2-3W. Virtually all DF trees in the District were infested, with topkilling noted in some of them. The moth population did not increase over that in 1948 except in localized areas. (R.E. LOCKHART, D.R., 11/14/49) (*U263*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Deerlodge	1949	Whitehall	15,0C	DF	In the Bigfoot Basin and Lower Whitetail Park in T.3-4N., R.4-5W. Continued from previous years, mainly on scattered host trees in Site VI DF. Some tree mortality was noted. Light infestation occurred in DF from Homestake Pass to Hells Canyon. (F.H. BLACKMER, D.R., 11/14/49) (*U263*)
	1953	Boulder	2,400	DF	All infested host stands in the Elkhorn Cr., Dry Cr., and Little Boulder R. areas were aerially sprayed with DDT in July. (R.E. LOCKHART, D.R., 9/25/53) (*U263*)
		Deerlodge	NR	DF,ES	Covered all DF types from the spread of the last two years. Defoliation was less severe this year in the Douglas Cr. and Dunkelburg Cr. drainages. (J.L. ROGERS, D.R., 9/26/53) (*U263*)
		Philipsburg	20,000	DF	Increased in severity during the past 2 years in host stands in T.6-9N., R.13-14W. Defoliation was heavy this year in privately-owned timberlands west of Philipsburg. Host types in Rock Cr. were not infested. (F.E. WILLIAMS, D.R., 9/28/53) (*U263*)
		Whitehall			Still in evidence in the Bigfoot Basin and Lower Whitetail Park (T.3-4N.,R.4-5W.) aerially sprayed with DDT in July 1953. Defoliation was currently severe in Hells Canyon with a probable loss of infested trees. Spread on the Pipestone Bench (T.2-3N.,R.6W.) and in the Bull Mts. (T.3N.,R.3W.) (G.R. WOLSTAD, D.R., 10/5/53) (*U263*)
Flathead	1933	Coram (Elk Park	NR	GF	Deep Cr. area; T.29N.,R.17W. Caterpillars were found on one tree only; no defoliation found anywhere in the District. (A.C. CAMPBELL, D.R., 11/16/33) (*U264*) "The spruce budworm infestation reported by Ranger Campbell is new to the Flathead. Campbell came...from the Selway (National Forest, Idaho) and should be able to identify the spruce budworm damage without question. It would seem probable, therefore, that his report is correct." (K. WOLFE For. Supv., 11/29/33) (*U264*)
	1942	Spotted Bear	1,200*	ES,SF	Gorge Cr. area, T.23N., R.16W. New; no tree mortality; believed to be spreading southwestward up Gorge Cr. (J.N. ROOT, D.R., 11/27/42) (*U264*)
	1943	Big Prairie	6,000*	DF,LPP,ES,WL	Big Salmon Cr. drainage, T.20-21N.,R.14-15W.; approximately 50% of the trees of each host species were infested. H.THOL, D.R., 10/9/43) (*U264*)
		Spotted Bear	1,200	ES,SF	Same as in 1942. (J.N. ROOT, D.R., 11/23/43) (*U264*)
	1944	Big Prairie	1[illegible],000	DF,LPP,ES,WL	In the Big and Little Salmon Rivers and Gordon Cr. drainages, T.19-22N.,R.14-15W. Epidemic status exists in the Gordon Cr. drainage where as many as 75% of the trees of various host species were infested in spots. (H.W. GODFREY, D.R., 11/30/44) (*U264*)
		Spotted Bear	1,200	ES	Abated this year in the Gorge Cr. drainage; now endemic. (L.J. ANDERSON, D.R., 10/30/44) (*U264*)
	1945	Big Prairie	30,000	DF,WL,ES,SF, LPP	Throughout host stands in the main drainage of the S.Fk. Flathead R. from Gordon Cr. to Little Salmon Park. Mostly endemic with smaller host trees defoliated more heavily. (H.W. GODFREY D.R., 12/7/45) (*U264*)
		Spotted Bear	4,000	ES,SF,DF,LPP	Approximately 3,000 acres of host types were newly infested this year in the Helen Cr. and Damnation Cr. drainages (T.22-23N.,R.14W.); defoliation heavy. The older infestation in Gordon Cr. continued to decline. (C. SHAW, Acting D.R., 11/3/45) (*U264*)
	1946	Big Prairie	60,000	ES,DF	Continuous throughout host stands in the main drainage of the S.Fk. Flathead R. from Babcock Cr. and Young Cr. to the Little Salmon R. (T.20-21N.,R.13-14W.). An aerial survey of infested areas was made by J. C. EVENDEN, Entomol., U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, and reported by him on 9/5/46. (R. T. CLONINGER, D.R., 11/22/46) (*U264*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Flathead	1946	Coram	NR	NR	Small, scattered patches of infestation were noticed throughout the District. No tree mortality was observed. (B.A. BEALEY, D.R., 11/12/46) (*U264*)
		Swan Lake	NR	NR	Isolated defoliation was noted throughout the District, but the infestation did not increase. (V.H. EASTMAN, D.R., 11/13/46) (*U264*)
	1947	Big Prairie	NR	ES,DF	Now present in all host stands throughout the District. Approximately 10% of all host trees under 6 inches d.b.h. were dead this year. Extent and intensity of infestations increased, but observed moth populations decreased in 1947. (R.T. CLONINGER, D.R., 11/12/47) (*U264*)
		Condon	NR	DF	Throughout the west slope of the Swan Range from Holland L. to Goat Cr. (T.19-22N.,R.16W.). Infestation is fairly old with newer infestations in the northernmost parts of the general infested area. New infestations noted in 1947. Host tree mortality from older infestations was heavy in isolated spots. (C.E. STILLWELL, D.R., 11/12/47) (*U264*)
		Spotted Bear	6,000	ES,SF,DF,LPP	Infestations reported in the Gorge Cr. drainage for the past 6 years were spreading. Host stands in the Helen Cr., Damnation Cr., and Snow Cr. drainages were badly infested, with some mortality among the younger host trees. Light infestations spread to stands in the White R. and the upper Spotted Bear R. areas and north along the S.Fk. Flathead R. to Spotted Bear Mt. in T.25N.,R.15W. (C. SHAW, Acting D.R., 11/14/47) (*U264*)
	1948	Big Prairie	NR	DF,ES	Observed throughout all DF-WL types. Host stands in the Danaher Cr. and Young Cr. drainages were newly infested. *Seemingly, stands on south- and west-facing slopes have suffered the greatest defoliation in most infested areas, with resultant killing of up to 100% of DF seedlings and saplings in many groups covering up to 2 acres in size. It is estimated that 15% of the mature DF trees have died from cumulative defoliation. ES trees have been lightly defoliated thus far in the outbreak.* (R.C. GARDNER, D.R., 12/1/48) (*U264*)
		Condon	NR	DF	Confined to upper parts of the west slope of the Swan Range. *This area probably was first infested by budworms invading through Smith Cr. Pass from severe infestations in the S.Fk. Flathead R. drainage.* (R.C. GARDNER, D.R., 12/1/48) (*U264*)
		Spotted Bear	6,000	ES,SF,DF,LPP	Decreased in the Gorge Cr., Helen Cr., Damnation Cr., and Snow Cr. areas, with about 10% of all of the host trees dead from cumulative defoliation. Now endemic in the White R., Spotted Bear R., and Spotted Bear Mt. areas. New infestations were noted this year on 2,000 acres on Green Mt. (T.25N.,R.14W.), with about 80% of the fir 50% defoliated. A few host trees were infested at the Spotted Bear R.S. (C. SHAW, D.R., 11/9/48) (*U264*)
		Swan Lake	NR	NR	Infestations very sparse. (V.H. EASTMAN, D.R.,11/9/48)(*U264*)
	1949	Big Prairie	50,000	DF,SF,ES,GF	All host types within the District have become infested, *with death of young age class trees amounting to as much as 100% on many of the drier sites; cumulative killing of mature trees is heavy on south-facing slopes. SF trees appear to be the most severely defoliated of the several host species. More timber has been killed or damaged from budworm feeding on the District in the past 7 years than from all known fires. The fire hazard will be very great and trail maintenance costs will increase in budworm-damaged stands.* (G.A. MARYOTT, Forester, 11/23/49) (*U264*)
		Condon	30,000*	DF	All DF timber types east of the Swan R. now have become infested. The first infestation west of the Swan R. was found this year in Sec. 23,T.21N.,R.17W. (R.C. GARDNER, D.R., 11/30/49) (*U264*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Flathead	1949	Spotted Bear	40,000	ES,DF,SF	All host types now infested except those in the upper 20 miles of the S.Fk. Flathead R. drainage. Infestations have steadily increased in severity and extent toward the east and north during the past few years. Many dead trees were observed in 1945-infested areas. All commercial host types in the District appear doomed if the outbreak does not abate or is not controlled. (C. SHAW, D.R., 11/23/49) (*U264*)
	1950	Condon	30,000	DF,ES,GF	Static. Considerably more dead DF saplings were noted in infested areas than in 1949, particularly at lower elevations. Losses of ES saplings and poles were reported by P.C. JOHNSON (Entomol., U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho) to be great along the south shore of Holland L. (R.C. GARDNER, D.R., 11/22/50) (*U264*)
		Spotted Bear	40,000	ES,DF,SF	No active infestations observed. (C. SHAW, D.R., 11/6/50) (*U264*)
		Swan Lake	6,000*	GF,SF	Epidemic in the Goat Cr., S. Lost Cr., Woodward Cr. drainage and at Soup Cr. Flats and Whitetail Lookout Station, with mild defoliation of upper crowns of understory trees. Spreading northward. (V.H. EASTMAN, D.R., 11/15/50) (*U264*)
Gallatin (Absaroka)	1925	Big Timber (Deer Creek, all)	NR	NR	Observed throughout the District; appeared to be declining. (H. M. CRANE, D.R., 11/13/25) (*U255*)
		Gardiner (Park, all)	40	ES,DF	Terminated on Crevice Mt., Sec. 22,T.9S.,R.9E. Appeared to be an extension of recent infestations in Yellowstone National Park. (C.H. JOHNSON, D.R., 11/14/25) (*U255*)
			NR	DF,ES	Considerable damage to host timber developed from budworm infestations in the District in 1922, 1923, and 1924, possibly even prior to 1922, with DF the favored host. *These infestations are now arrested, possibly from the cold winter of 1923-24 and 1924-25 which may have killed hibernating budworm larvae.* Many defoliated trees may survive. (G.E. MARTIN, For. Supv., 11/23/25) (*U255*)
		Livingston (Yellowstone, N3/4)	NR	DF,ES	Infestations similar to those above were also reported in the Mill Cr. drainage during the period 1922-24. (G.E. MARTIN, For. Supv., 11/23/25) (*U255*)
	1926	Big Timber (Deer Cr., all)	NR	DF	Only occasional scattered infested trees were seen. (H.M. CRANE, D.R., 11/8/26) (*U255*)
Gallatin	1927	Bozeman (Bridger, all)	160*	DF	New and increasing in the Jackson Cr. drainage (Sec. 20, T.1S.,R.8E.) (L.E. EWAN, JR., D.R., 11/21/27) (*U265*)
		Livingston (Yellowstone, all)	1,000*	DF,ES	Fridley (Strickland) Cr. (Secs. 25-27, 34-36; T.5S.,R.7E.); increasing trend. (W.W. WETZEL, D.R., 11/4/27) (*U265*)
	1928	Bozeman (Bridger, all)	1,120*	DF	Decreased to endemic status on 160 acres in V Canyon (Secs. 31-32; T.1N.,R.6E.). *Discovered by settlers in August 1923, increased in extent and severity until 1926, then subsided.* Decreasing on 160 acres in Corbly Canyon (T.5-6N.,R.6E.); may not be budworm. On 640 acres in the Brackett Cr. and Stone Cr. areas (Secs. 4-5; T.1N.,R.7E.; Secs. 10-11;T.1S., R.7E.); may not be budworm. Decreasing on 160 acres in the Jackson Cr. drainage (Secs. 20-21;T.1S.,R.8E.). (Damage to trees in these four areas may have been caused by *Chermes cooleyi*.--Authors.) (L.E. EWAN, JR., D.R, 11/26/28) (*U265*)
		Livingston (Yellowstone, all)	1,000*	DF,ES	In the Fridley Cr. drainage (Secs. 25-27,34-36;T.5S.,R.7E.), 4 years old, increasing. (W.W. WETZEL, D.R.,10/4/28)(*U265*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Gallatin	1929	Livingston (Yellowstone, all)	1,000	DF,ES	Same area as above; decreasing. (W.W. WETZEL, D.R., 10/9/29) (*U265*)
	1930	(Yellowstone, all)	1,000	DF,ES	Same area as above; decreasing. (W.W. WETZEL, D.R., 10/1/30) (*U265*)
	1931	Livingston (Gallatin, all)	NR*	ES	(E.P. WHITE, D.R., 11/20/31) (*U265*)
		Livingston (Yellowstone, all)	1,000	DF,ES	Fridley Cr. area (see 1928 location); decreasing. (A. CRAMER, D.R., 11/17/31) (*U255*)
	1932	Livingston (Yellowstone, all)	1,000	DF,ES	Fridley Cr. area; decreasing. (A. CRAMER, D.R., 11/15/32) (*U255*)
Gallatin (Absaroka)	1932	Bozeman (Shields, W1/2)	NR	DF,SF	Common over most of the District. Host trees averaging 8 inches d.b.h. have been considerably damaged over a number of years. Infestations appear to be increasing. (C.V. RUBOTTOM, D.R., 11/10/32) (*U255*)
		Livingston (Shields, E1/2)	NR	DF,SF	Same as above. (C.V. RUBOTTOM, D.R., 11/10/32) (*U255*)
	1933	Bozeman (Shields, W1/2)	NR	DF,SF	Static. Infested trees averaging 4 to 8 inches d.b.h. were common throughout the District. Considerable timber has been killed, but values are small. Control measures are not justified. (C.V. RUBOTTOM, D.R., 11/6/33) (*U255*)
		Livingston (Shields, E1/2)	NR	DF,SF	Same as above. (C.V. RUBOTTOM, D.R., 11/6/33) (*U255*)
Gallatin		Livingston (Yellowstone, all)	1,000	DF,ES	Fridley Cr. (see 1928 location); static. *About 2% of the number of host trees infested have died since the infestation began in 1924.* Control believed to be impractical. (A. CRAMER, D.R., 11/21/33) (*U255*)
Gallatin (Absaroka)	1934-35, 1937-38	Bozeman (Shields, W1/2)	NR	DF,SF	Same as in 1933. (C.V. RUBOTTOM. D.R., 11/2/34, 11/13/35, 12/8/37, 11/16/38) (*U255*)
		Livingston (Shields, E1/2)	NR	DF,SF	Same as in 1933. (C.V. RUBOTTOM, D.R., 11/2/34, 11/13/35, 12/8/37, 11/16/38) (*U255*)
Gallatin	1941	Bozeman (Bridger, all)	20,000	DF,SF	First-year infestations were seen in the Brackett Cr., Fairy Lake Cr., Frazier Cr., and Bridger Cr. drainages on host saplings and trees up to 18 inches d.b.h. and larger. Some trees were severely defoliated, most only moderately so. *No current cones are being produced on infested trees; surmised that this may be related to budworm feeding. Many new cones are aborted on infested trees; although cone moths may have caused this.* DF is the favored host. The severest infestation was in the Brackett Cr. drainage in Secs. 31-32, T.2N.,R.7E., and in Secs. 25-26, T.2N.,R.6E. (L.E. EWAN, D.R., 11/15/41) (*U265*)
	1942	Bozeman (Bridger, all)	NR	DF,SF,ES	Spread over the entire District. *Either no cones were produced, or they were aborted, in areas of severest infestation. Crows were observed feeding on budworm "millers" (moths) in August on the north slope of Battle Ridge.* (L.E. EWAN, D.R., 11/17/42) (*U265*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Gallatin	1942	Hebgen Lake	NR	SF	In the Sheep Cr. drainage in Sec. 17, T.12S.,R.3E. Defoliation was observed and budworm feeding was suspected as the cause. (A.H. ABBOTT, For. Supv., 12/4/42) (*U265*)
	1943	Bozeman (Bridger, all)	NR	NR	*"Red belt" frost damage during the winter of 1942-43 is reported in August to have killed terminal buds and prevented growth of 1943 foliage on host trees in a budworm-infested area near SW1/4 Sec. 8, T.1N.,R.7E. Budworm populations appear to have been drastically reduced. No follow-up infestation by bark beetles was observed in the frost-weakened trees.* (B.A. ANDERSON, For. Supv., correspondence to the Regional Forester, 12/20/43) (*U265*)
	1944	Bozeman (Bridger all)	NR	DF,SF,ES	Host stands badly infested in former years throughout the District appeared to be recovering, although all host trees were dead in scattered areas of up to 40 acres in size in the Brackett Cr., Weasel Cr., Skunk Cr., and Cache Cr. drainages. Currently, infestations are subsiding in the Battle Ridge and Cache Cr. areas while increasing in severity in other areas, notably Secs. 10, 16, 28, 33, 34;T.1N.,R.7E in Secs. 30-32; T.1S.,R.8E.; and in Secs. 2, 11;T.3N.,R.6E. Defoliation in these latter areas is severe for the first time. Current infestations were generally severe in the District. (L.E. EWAN, D.R., 11/27/44) (*U265*)
		Bozeman (Bozeman, all)	NR	DF,ES	Static; infestations were present throughout the District. (A.J. KRAMIS, D.R., 11/23/44) (*U265*)
	1945	Bozeman (Bozeman, all)	NR	DF,SF,ES	All host stands were infested in the Bridger Mts. Unit and in Sec. 21 and Sec. 28; T.3S.,R.7E. of the Bozeman Unit. In the Bridger Mts. Unit, infestations were subsiding north of Olson Cr. and increasing in the White Cr., Stone Cr., Jackson Cr., Spring Cr., Fleshman Cr., and Perkins Cr. drainages. *Infestations in the Bozeman Unit are just beginning, principally on south-facing slopes.* (L.E. EWAN, D.R., 11/19/45) (*U265*)
	1946	Bozeman (Bozeman, all)	NR	DF,ES	Generally subsided, except in the Stone Cr. drainage in Secs. 10-12; T.1S.,R.7E., where an increasing trend was noted. (L.E. EWAN, D.R., 11/26/46) (*U265*)
	1947	Bozeman (Bozeman, all)	NR	DF,ES	No new infestations; previously infested stands appeared to be recovering. (L.E. EWAN, D.R., 11/17/47) (*U265*)
	1948	Bozeman (Bozeman, all)	30,000	DF	Increased, with moths very abundant during flight period in the Bridger Cr., Stone Cr., Spring Cr., and Jackson Cr. drainages. Infested acreages within the Forest were estimated to be 11,000 in T.1N.,R.7E., and 7,000 in T.1S., R.8E. An estimated 5,000 acres were infested outside but adjacent to the Forest. (E.D. WHITE, for L.E. EWAN, D.R., 11/10/48) (*U265*)
	1949	Bozeman (Bozeman, all)	NR	NR	Declined, with less defoliation apparent in stands in the Bridger Cr. and Jackson Cr. drainages. (J.C. URQUHART, For. Supv., memorandum to the Regional Forester, 10/28/49) (*U265*)
		Livingston (Yellowstone, N3/4)	NR	DF	Infestation in Sixmile Cr. was confirmed 10/28/49 by P.C. JOHNSON, Entomol., U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho. (J.C. URQUHART, For. Supv., memorandum to Regional Forester) (*U265*)

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ational orest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
allatin	1950	Livingston (Yellowstone, N3/4)	NR	NR	Declined throughout the Forest; very little activity observed. (J.C. URQUHART, For. Supv., memorandum to the Regional Forester, 11/28/50) (*U265*)
	1951	Bozeman (Bozeman, all)	NR	DF,SF,ES,LPP	Older infestations declined in the Bridger Cr., Stone Cr., Spring Cr., White Cr., and Jackson Cr. drainages. New infestations developed this year in the Lyman Cr. and Chum Cr. drainages (T.1S.,R.6E.) on the west slope of the Bridger Range and in the Rocky Canyon and Francham Mt. areas (T.2S.,R.7E.) south of U.S. Highway 10. (H.D. HALPIN, D.R., 10/9/51) (*U265*)
		Bozeman (Shields, W1/2)	NR	DF,SF,ES,LPP	Infestations were observed throughout the District, primarily in DF stands. Moths were seen to be abundant in the upper Willow Cr. drainage in T.1S.,R.8E. (F.B. HALLER, D.R., 10/8/51) (*U265*)
		Gardiner	600	DF	Beattie Gul. south to Stevens Cr. (T.9S.,R.8E.), mostly within Yellowstone National Park, and west to the Mol Herron Cr. drainage (T.9S.,R.7E.), mostly on private lands. (D.E. NIVEN, For. Aid, 10/8/51) (*U265*)
		Livingston (Shields, E1/2)	NR	DF,SF,ES,LPP	Infestations observed throughout the District, primarily in DF stands. (F.B. HALLER, D.R., 10/8/51) (*U265*)
	1953	Bozeman (Bozeman, all)	NR	DF	Declined in severity in the Ross Cr., N. Cottonwood Cr., Bridger Cr., Spring Cr., Stone Cr., and Jackson Cr. drainages (T.1N.,R.6E.; T.1-2S.,R.6-8E.) (H.D. HALPIN, D.R., 11/17/53) (*U265*)
		Bozeman (Shields, W1/2)	NR	DF	Decreased to endemic status along the east slope of the Bridger Range from Willow Cr. north to Sixteen Mile Cr. (F.B. HALLER, D.R., 11/13/53) (*U265*)
		Gardiner	1,500	DF	Decreased in severity in areas reported in 1951 and in Bassett Cr. (T.8-9S.,R.7-9E.). (J. MORRISON, D.R., 11/4/53) (*U265*)
		Livingston (Yellowstone, all)	NR	NR	Less active than in 1952. See report for 1949. (D.W. NELSON, D.R., 11/10/53) (*U265*)
elena	1925	Townsend (Deep Cr. all)	5,000*	DF	Approximately 75% of DF trees under 18 inches d.b.h. were infested in the Cabin Gulch and Russell Fk. Deep Cr. drainages in Secs. 10-14, 23, 24; T.7N., R.4E.; and in Secs. 7, 17-19; T.7N.,R.5E. Infested DF timber in one 40-acre tract in Sec. 12 above was a "total loss." Infestations are increasing. (E.V. WELTON, D.R., 9/30/25) (*U266*)
	1926	Townsend (Deep Cr., all)	7,000	DF	Increased in the Cabin Gulch area in Secs. 10-14, 23-26; T.7N.,R.4E.; and in Secs. 7,18-19;T.7N.,R.5E. Hundreds of DF seedlings and saplings have been killed; 40- to 80-year-old DF trees are dying and will not survive another year of defoliation in numerous areas up to 40 acres in size. *Younger trees are more seriously infested.* (E.V. WELTON, D.R., 11/13/26) (*U266*)
	1927	Townsend (Deep Cr., all)	7,500*	DF	In the Cabin Gulch, Russel Fk., Deep Cr., and the south side Deep Cr. areas in Secs. 10-14, 23-26; T.7N.,R.4E.; and in Secs. 7,18-20;T.7N.,R.5E. Host trees up to the 30- to 40-year-old age classes comprised most of those infested. *Defoliation and tree mortality was the most severe on south-east-facing slopes, with DF timber a "total loss" on areas up to 40 acres in size.* (E.V. WELTON, D.R., 11/11/27) (*U266*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Helena	1928	Townsend (Deep Cr., all)	8,500	DF	Generally in the same areas as in 1927. (E.V. WELTON, D.R., 11/10/28) (*U266*)
	1929	Townsend (Deep Cr., all)	9,000*	DF	In the 1927- and 1928-infested areas and 80 acres additional in Sec. 25; T.6N.,R.4E. infested in 1929. (E.V. WELTON, D.R., 11/6/29) (*U266*)
	1930	Canyon Ferry (Duck Cr., N3/4)	8,000*	DF	First-season infestations observed to be increasing in the Dry Range, Avalanche Butte, and Duck Cr. areas in Secs. 13-15,21-24;T.12N.,R.3E.;Secs. 18-19,30-31; T.12N., R.2E.; Secs. 25-26;T.12N.,R.1E.; and Secs. 24-26,35-36;T.9N.,R.3E. (C.F. MARTINEAU, JR., D.R., 11/14/30) (*U266*)
		Townsend (Deep Cr., all)	12,000*	DF	In the Deep Cr., Sulphur Bar Cr., Dry Cr., and Haw Gulch drainages (Secs. 10-15,22-27;T.7N.,R.5E.; Secs. 8,17,30; T.6N., R.5E.; Secs. 25,36;T.6N.,R.4E.; and Secs. 22,27,34; T.5N.,R.4E. Some budworm defoliation may be seen anywhere in the District. *Infestations of spruce spider mite were noted on DF trees in several small areas in Secs. 3,24; T.5N.,R.4E.; and in Sec. 25; T.6N.,R.4E.* (E.V. WELTON, D.R., 11/14/30) (*U266*) *Spider mites and their eggs attracted large numbers of yellow jacket wasps and ants. Ants worked industriously on mite-infested trees while yellow jackets hovered about. It is supposed that the mites were used to "fill the larders" of the ants and yellow jackets.* (L.C. HURTT, For. Supv., memorandum to Regional Forester, 11/25/30) (*U266*)
	1931	Canyon Ferry (Duck Cr., N3/4)	10,000	DF	Very light throughout the District. (C.F. MARTINEAU, JR., D.R., 11/16/31) (*U266*)
		Townsend (Deep Cr.; Crow Cr.; Duck Cr., S1/4)	14,000*	DF	In the 1930-infested areas and in the Rocky Canyon drainage in Secs. 10-15,22-27;T.7N.,R.4E.;Secs. 17-20,30;T.7N.,R.5E.; Secs. 8,17,30;T.6N.,R.5E.; Secs. 25,36;T.6N.,R.4E.; and Secs. 22,27,29,34;T.5N.,R.4E. Infestations slightly increased in extent but with less damage. *Spider mite infestations static.* (E.V. WELTON, D.R., Deep Cr.-Crow Cr. R.D., 11/2/31) (*U266*)
	1932	Canyon Ferry (Duck Cr., N3/4)	NR	DF	Very light throughout the District; no trees killed since 1930. (C.F. MARTINEAU, JR., 11/14/32) (*U266*)
		Townsend (Townsend, all; Duck Cr.,S1/4)	14,000	DF	Same as in 1931. (E.V. WELTON, D.R., Townsend R.D., 11/11/32; C.F. MARTINEAU, JR., D.R., Duck Cr. R.D., 11/14/32) (*U266*)
	1933	Townsend (Townsend, all)	12,100	DF	In the Cabin Gulch, Deep Cr., Dry Cr., and Sixteen Mile Cr. drainages in parts of T.5-7N.,R.3-5E. "After an attack of several seasons, areas of 40 to 60 acres of seedlings, saplings, and young growth have been totally destroyed on the Cabin Gulch drainage. Direction of spread has been to the south....During the present season the attack seems to have subsided, but groups of trees within the affected areas and on the outside borders of all previously reported areas, and on areas where the attack was made two and three years ago, were attacked again this year. Infested trees occur in groups, and usually a 100% stand of young growth will be killed. *It seems that successive attacks from year to year will usually prove fatal to at least 60% of the trees up to 10 inches in diameter. Four to 8 years is usually the time*

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tional : rest	: Year	: Ranger district	: Infested acreage	: Host tree species	: Pertinent infestation conditions, reporter, and references
lena	1933	Townsend (Townsend, all) (con.)			*it takes to kill the larger-sized trees.* In the spring affected areas usually show up grey, but along in July these affected areas begin to turn reddish in color. A few small areas of new attacks were noticed during the 1933 season, and the attack within the old affected areas did not seem to be so extensive this year as in previous years." (E.V. WELTON, D.R., 11/16/33) (*U266*)
	1934	Townsend (Townsend, all)	12,100	DF	Same as in 1933; decreasing severity. *After the second or third year of attack, host timber acquires a grayish color.* (E.V. WELTON, D.R., 11/7/34) (*U266*)
	1935	Townsend (Townsend, all)	13,000*	DF	Same as in 1934; slight increase in severity. No large amounts of timber are being killed. (E.V. WELTON, D.R., 11/8/35) (*U266*)
	1936	Townsend (Townsend, all)	13,000	DF	Decreased with no spreading in parts of the Big Belt Mts. within T.7N.,R.4-5E.;T.6N.,R.4-5E.; and T.5N.,R.4E. Only seedlings and a few saplings were killed this year. (E.V. WELTON, D.R., 11/10/36) (*U266*)
	1937	Townsend	13,000	DF	In the Big Belt Mts., as above; continued in previously infested areas with some tree killing. (E.V. WELTON, D.R., 11/8/37) (*U266*)
	1938	Townsend	13,000	DF	Increased in severity, with a definite brownish cast to the timbered landscape throughout most of the Big Belt Mts. Division of the District. (E.E. LUER, Asst. D.R., 11/14/38) (*U266*)
	1939	Townsend	13,000	DF	Continued; most prevalent in the Deep Cr. and Cabin Gulch drainages. No great amount of new tree killing. (C.W. WETTERSTROM, Acting D.R., 11/10/38) (*U266*)
	1940	Townsend	13,000	DF	Continued; most prevalent in the Cabin Gulch, Deep Cr., and Hay Cr. drainages. No large areas of new tree killing developed. Most of the dead timber from previous infestations is in Sec. 25; T.6N.,R.4E.; and Secs. 4,8,9,19-21; T.6N.,R.5E. Most of this timber has been dead for several years. (E. E. LUER, D.R., 11/13/40) (*U266*)
	1941	Townsend	15,000	DF	Continued; mostly in DF type in the Hay Cr. and Deep Cr. drainages and surrounding Grassy Mtn. in T.6-8N.,R.4-5E. (E. E. LUER, D.R., 11/8/41) (*U266*)
	1942	Townsend	20,000	DF	Increased in severity and extent; noted this year in the Kentucky Gulch and Thomas Gulch drainages near Benton Guard Station. Trees up to 24 inches d.b.h. and larger have been killed from repeated defoliation on the east slope of Grassy Mt. in Sec. 33; T.7N.,R.5E., and in Sec. 4; T.6N.,R.5E. (E. E. LUER, D.R., 11/12/42) (*U266*)
	1943	Townsend	NR	DF	The infestation, now 10 years old, increased most rapidly in the last 2 years and now covers almost all the DF type in the Big Belt Mts. Unit of the District, as well as in large sections of the Slim Sam Cr., Crow Cr., and Beaver Cr. drainages in the Elkhorn Mts. Unit. *No evidence was found of any bark beetle infestations in budworm-damaged stands. "Areas of dead timber due to 'red belt' winter kill (of DF trees) should not later be confused with this (budworm) infestation, as it now appears that about 80% of the timber in the 'red belts' will die."* (C.A. MacGREGOR, D.R., 11/15/43) (*U266*). (Massive amounts of dead timber from the 1942-43 winter kill were still to be seen in 1968, some fallen, but much of it still standing, on the divide between Greyson Cr. and Dry Cr. near the west boundary of the Forest.--Authors.)
	1944	Townsend	NR	DF	Continued throughout the District. *"Contrary to expectations, the epidemic condition did not slacken last year following the winter kill (of DF trees) of 1942-43."* (C.A. MacGREGOR, D.R., 7/17/45) (*U266*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Helena	1945	Canyon Ferry	65,000*	DF	First-year epidemics were observed in the Candle Mt., Trout Cr., Magpie Cr., and the upper Avalanche Cr., Whites Gulch, and Cement Gulch areas. Continuing endemic infestations were seen in the lower parts of Whites Gulch and Avalanche Cr. drainages, in other parts of the Trout Cr. and Magpie Cr. drainages, and in the Willow Cr. and east side of Beaver Cr. drainages. Large flights of moths were observed in July coming from a southerly direction. Infestations generally were increasing in extent and severity, but no host tree mortality has been observed as yet. (J. R. JANNSON, D.R., 11/14/45) (*U266*)
		Helena	600	DF	In the Park Gulch and Skelly Gulch areas (T.11N.,R.5W.) outside of the Forest. *A flight of budworm moths was noted August 5, 1945 traveling in a northwesterly direction over a strip of land approximately 1/4 mile wide and 4 miles long.* Most of the DF reproduction in this strip was attacked (probably in the previous year, or years--Authors). (V.J. EDWARDS, D.R., 11/13/45) (*U266*)
		Townsend	NR	DF	Continued unchanged throughout the District except for a slight increase in extent. The largest area of budworm-killed timber since the start of the outbreak on this District was that reported in 1940 on the eastern slope of Grassy Mt. *In areas of "red belt", or winter kill (of DF trees) in 1942-43, it is difficult to determine the cause of the death of the trees (i.e., whether by budworm defoliation, climatic conditions, or a combination of these or other causal factors.*--Authors). (C.A. MacGREGOR, D.R., 11/25/45) (*U266*)
	1946	Canyon Ferry	75,000	DF	Infested areas continued as listed in 1945 and added areas of infested trees were seen in the Vermont Gulch drainage this year. Host stands in parts of Whites Gulch and Hellgate Gulch are now almost completely defoliated from continuing infestations of recent years. *Some DF stands damaged by frost ("red belt", or winter kill) in the winter of 1942-43 have been attacked by budworms. The trees in these stands are now completely defoliated and appear to be dying.* The increase in the general epidemic was not as rap this year as it was in 1945. Not many DF stands in the District remain uninfested. (J.R. JANNSON, D.R., 11/19/46) (*U266*)
		Helena	600	DF	In the Park Gulch and Skelly Gulch drainages; spread this year into the headwaters of Little Prickly Pear Cr. in T.11N.,R.5E. Heaviest damage is to DF reproduction. (E.P. WHITE, D.R., 11/26/46) (*U266*)
		Townsend	NR	DF	Epidemic throughout all host stands in the District. No new budworm-caused tree mortality observed. (C.A. MacGREGOR D.R., 11/7/46) (*U266*)
	1947	Canyon Ferry	75,000	DF	All DF stands in the District are now infested. Infestatio is generally declining. *About 90% of the host trees are no dead in stands damaged in the winter kill of 1942-43 and subsequently infested by the budworm. An example of this are stands in the vicinity of old Whites City in Whites Gulch.* (L. R. OLSEN, Forester, 11/21/47) (*U266*) Extensive infestations were encountered throughout the Dry Range and in numerous areas along the eastern timber fringe of the Big Belt Mts. Defoliation was severe in places, amounting to "almost total devastation of very large areas" of host forests. (C.C. STRONG, Chief, Div. of Information and Education, Regional Office, Missoula, Mont., memorandum of 8/12/47 to J.C. EVENDEN, Entomologist, Bur. of Entomol. and Plant Quar., Coeur d'Alene, Idaho) (*U266*)
		Helena	NR	DF	Throughout all DF stands on the District. (E.P. WHITE, D.R. 11/20/47) (*U266*)
		Townsend	NR	DF	Same as in 1946; decreasing trend. (A. D. MOIR, For. Supv. memorandum to the Regional Forester, 11/28/47) (*U266*)

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tional rest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
lena	1948	Canyon Ferry	75,000	DF	In Whites Gulch, Avalance Cr., east side Beaver Cr., Magpie Cr., Trout Cr., Vermont Gulch, and Willow Cr. drainages; static. (J.L. ROGERS, Forester, 11/2/48) (*U266*)
		Helena	NR	DF,SF,ES	Throughout the District, with attacks heaviest east of the Continental Divide. SF trees were heavily defoliated. (E.P. WHITE, D.R., 11/22/48) (*U266*)
	1949	Canyon Ferry	80,000	DF	Throughout all host stands on the District southeast of Soup Cr. along the west slope of the Big Belt Mts.; also in the Vermont Gulch and Beaver Cr. drainages along the east slope of the Big Belts. The most heavily damaged stands were in the Whites Gulch, Avalanche Cr., Bilk Gulch, upper Magpie Cr., and upper Trout Cr. drainages. Infestations static. *Many trees repeatedly defoliated are now dying or are being attacked and killed by the Douglas-fir beetle in parts of the upper Trout Cr., Whites Gulch, and Spring Gulch (where 40% of the DF trees marked for sawlog cutting during the past six months were dead and an additional 40% are currently infested), upper Willow Cr., Cottonwood Gulch, and Sweats Gulch drainages.* (J.L. ROGERS, Asst. D.R., 10/24/49) (*U266*)
		Helena	NR	DF,SF	Throughout all host types on the District; heaviest in the Little Prickly Pear Cr. drainage from Austin Station (N.P.R.R.) to Granite Butte (T.11N., R.5-6W.;T.12N.,R.6-7W.; and T.13N.,R.7W.). Some smaller trees were dying from successive defoliation. Lightest infestations were noted in the Little Blackfoot R. drainage west of the Continental Divide. (E.P. WHITE, D.R., 10/27/49) (*U266*)
		Townsend	NR	DF	Throughout all DF stands on the District, but principally centered in the Big Belt Mts. in areas totalling 30,000 acres of National Forest and 6,000 acres of privately-owned timberlands within the Forest. Infested areas, by priority of damage, include the following drainages: Ray Cr.-Deep Cr., 15,000 acres; Benton Gulch, 6,000 acres; Faulkner Cr.-Hay Cr. (east slope of Grassy Mt.), 6,000 acres; Dry Cr.-Greyson Cr., 5,600 acres; Gurnett Cr., 900 acres. (G.N. Engler, Acting D.R., 10/21/49) (*U266*) Budworm control measures are believed imperative at the earliest possible date to stop infestations now in all DF stands east of the Continental Divide and in some to the west; also possibly those of the Douglas-fir beetle. (A.D. MOIR, For. Supv., 10/31/49) (*U266*)
	1951	Canyon Ferry	NR	NR	Intensity declined throughout the District. A budworm survey this year by R.E. DENTON (Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho) was cited. (W.R. FALLIS, D.R., by C.M. HOFFERBER, 12/2/51) (*U266*)
		Lincoln	5,000	DF	In the Canyon Cr., Tarhead Cr., and Trout Cr. drainages, south to Marsh Cr. along the east slope of the Continental Divide (T.14N.,R.6W.). Infestations began in 1948, increasing in area each year. Infestations in the Beaver Cr. and Stonewall Cr. drainages have been dormant for the last two years. (J.W. VENRICK, D.R., 10/11/51) (*U266*)
		Townsend	48,000	DF	All host type within the District has become infested in recent years. The heaviest infestations reported were in 1946 and 1947. A heavy moth flight this year was described in a special report on 8/20/51. A budworm survey this year by R.E. DENTON was cited. (V.J. EDWARDS, D.R., 10/1/51)(*U266*) All DF stands throughout the Forest area have become infested, but none severe enough to cause tree mortality. Infestations appeared to be declining, except those increasing in the Marysville, Nevada Cr., and Colorado Mt. areas. Control was not recommended because of the high cost of successfully treating the vast infestations. *Attacks of the Douglas-fir beetle have almost vanished from the Forest, but surveillance will be continued to detect any increase in them in trees weakened by budworm defoliation.* (A.D. MOIR, For. Supv., 10/12/51) (*U266*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Helena	1953	Canyon Ferry	200,000	DF	Continued throughout all host type on the District; most severely in all timbered drainages of the Missouri R. Mortality of young DF trees was very heavy on 800 acres near the head of the Soup Cr. and Bear Trap Cr. drainages; other tree mortality was noticed in DF stands in the Avalanche Cr., Cave Gulch, and Hellgate Gulch drainages. Other heavily infested stands this year were observed in the Moore Cr., Gates of the Mountains Wild Area, Trail Gulch, and Fuller Mt. localities and in the Horse Gulch area in the Smith R. country. (W.R. FALLIS, D.R., 10/9/53) (*U266*)
		Lincoln	NR	DF	In all DF stands throughout the District; particularly evident in the Lincoln Valley south of Montana Highway 20 and in the vicinity of Flesher Pass, Poorman Cr., and Nevada Cr. New, light infestations were noted in the Keep Cool Cr. and Sucker Cr. drainages. (L.R. OLSEN, D.R., 10/14/53) (*U266*)
		Townsend	48,000	DF	Continued throughout all DF stands on the District. The moth flight appeared lighter this year. (V.J. EDWARDS, D.R., 10/6/53) (*U266*)
Kootenai	1939	Fortine	NR	ES	In the Grave Cr., Foundation Cr., Stahl Cr., and Clarence Cr. drainages; a widespread but light infestation exists in all age classes of host trees. (S.H. LARSON, D.R., 11/24/39) (*U268*)
Lewis & Clark (Absaroka)	1926		NR	NR	*"The spruce budworm, whose activities have been so much in evidence on the Forest in former years, has almost entirely disappeared."* (E.H. MYRICK, For. Supv., 11/26/26) (*U255*)
	1932	Mussellshell (Shields, N1/3)	NR	DF,SF	Infested host trees were common throughout the District, mainly in T.5-7N.,R.9-10E.; infestations increased. Defoliation over a number of years has caused considerable damage to host trees. (C.V. RUBOTTOM, D.R., 11/10/32) (*U255*)
	1933	Musselshell (Shields, N1/3)	NR	DF,SF	Continued in all host types. Considerable timber has been killed, but values are small. No control was recommended. (C.V. RUBOTTOM, D.R., 11/6/33) (*U255*)
	1934	Musselshell (Shields, N1/3)	NR	DF,SF	Same as in 1933. (C.V. RUBOTTOM, D.R., 11/2/34) (*U255*)
	1935	Musselshell (Shields, N1/3)	NR	DF,SF	Concentrated in some localities, but generally declining. (C.V. RUBOTTOM, D.R., 11/13/35) (*U255*)
	1937	Musselshell (Shields, N1/3)	NR	ES	In host seedlings and trees up to 8 inches d.b.h. throughout the District. (C.V. RUBOTTOM, D.R., 12/8/37) (*U255*)
	1938	Musselshell (Shields, N1/3)	NR	ES	Same as in 1937, with infested trees being distorted but not killed. (C.V. RUBOTTOM, D.R., 11/16/38) (*U255*)
Lewis & Clark	1938	Teton	NR	ES	Possibly 25% of the ES saplings throughout the District were infested. Infestations increased this year over those of previous years. No host trees were killed in 1938. (G.H. DUVENDACK, D.R., 11/16/38) (*269*)
	1944	White Sulphur	NR	ES	In the Smith R. drainage (T.11-12N.,R.5-7E.). Infested trees were quite noticeable, but appeared only slightly injured. (C.W. JACKSON, Asst. For. Supv., 11/15/44)(*U269*)
	1945	White Sulphur	1,100	DF	In the Tenderfoot Cr. drainage (T.13-14N.,R.5E.), 1,000 acres, and in the Miller Gulch and upper Newlin Cr. drainages, 100 acres. Insect specimens collected by the District Ranger were subsequently identified as the spruce budworm. (B.L. HURWITZ, D.R., 11/11/45) (*U269*)

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ational orest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
ewis & lark	1946	Musselshell	NR	DF	"This (unknown) defoliating insect (probably budworm--Authors) is found throughout DF stands on the District, and, while the actual damage does not appear great at this time, it may be a future threat to our DF (stands)..." (G.R. ROSKIE, D.R., 11/13/46) (*U269*)
	1947	Belt Creek, Judith, & White Sulphur	NR	DF	Annual attacks are continuing in DF stands throughout the Little Belt Mts. and the Crazy Mts. on these three Districts, but with little evidence of immediate host tree mortality. (F.O. LEFTWICH, For. Supv., memorandum to the Regional Forester, 11/28/47) (*U269*)
	1948	Musselshell	NR	DF	Same as in 1947. (J.S. FORSMAN, D.R., 11/10/48) (*U269*)
	1949	White Sulphur	NR	DF	Wide spread throughout the District; not decreasing, and with no host tree mortality as yet. (B.L. HURWITZ, D.R., by F.T. BAILEY, 11/18/49) (*U269*)
	1950	Musselshell			Now infesting more than 60% of all host types. The peak of the infestation was reached in 1949 and it is now declining. (M.O. WATKINS, Acting For. Supv., 8/3/50) (*U269*)
					Throughout DF stands in the Castle Mts. and the Spring Cr. area of the Little Belt Mts.; declined in severity. (J.S. FORSMAN, D.R., 11/20/50) (*U269*)
		Sun River	6,000	DF,SF	In the Willow Cr. and Ford Cr. drainages (T.19-20N.,R.8-9W.). Most host trees at lower elevations and bordering the Sun R. plains were attacked. (M.O. WATKINS, Acting For. Supv., 8/3/50) (*U269*)
					Throughout the foothill DF stands and in the Loaf Cr. drainage. (D.C. MORRISON, D.R., 11/14/50) (*U269*)
		Teton	NR	DF	In the host type scattered throughout the foothills of the Rocky Mts. (J. F. HINMAN, D.R., 11/15/50) (*U269*)
		White Sulphur	NR	DF	Widely scattered throughout the District, but declining in severity. (G.A. MARHT, D.R., 11/8/50) (*U269*)
	1951	Musselshell	NR	DF	Rebuilding rapidly; heavy (defoliation) in 1951 in all DF stands in the Castle Mts. and Little Belt Mts. Spread this year to DF stands in the Crazy Mts. (J.S. FORSMAN, D.R., 10/2/51) (*U269*)
		White Sulphur	5	DF	In the Miller Gulch drainage (T.11N.,R.7E.) in a few scattered trees. (G. HOLMES, ACTING D.R., 10/6/51) (*U269*)
	1953	Musselshell	NR	DF	Declined in severity in areas infested in 1952 in the Castle Mts., Little Belt Mts., northwestern part of the Crazy Mts., and the Spring Cr. drainage. (J.A. FORSMAN, D.R., 9/18/53) (*U269*)
		White Sulphur	NR	DF	Nearly all DF stands on the District were infested to some degree. Severe defoliation with accompanying host tree mortality was noted in Secs. 13,24; T.11N.,R.6E. and in Secs. 18-20; T.11N.,R.7E. (G.A. MARHT, D.R., 9/18/51) (*U269*)
olo	1930	Superior (Quartz, all)	200	SF,WL,ES	In the W.Fk. Fish Cr. drainage. (G.H. HANKINSON, D.R., 11/15/30) (*U270*)
	1938	Seeley Lake	NR	ES	In the Clearwater R. and tributary drainages; only very slight host mortality was observed in the 5- to 20-year age class trees.(W.K. SAMSEL,L, D.R., 11/11/38) (*U270*)
	1939	Seeley Lake	NR	ES	Same as in 1938. (W.K. SAMSELL, D.R., 11/10/39) (*U270*)

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Table 4. (con.)

National Forest	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Lolo	1940	Seeley Lake	NR	ES	Same as in 1938. (W.K. SAMSELL, D.R., 11/4/40) (*U270*)
	1941	Seeley Lake	NR	ES	Apparently terminated with no noticeable host tree damage. (W.K. SAMSELL, D.R., 11/14/41) (*U270*)
	1946	Seeley Lake	70,000*	DF,ES,SF,LPP	Concurrent infestations of the hemlock looper and the budworm (latter insect's role not defined.--Authors) defoliated seedlings and saplings in small groups in the lower parts of the Placid Cr., Deer Cr., Marshall Cr., Colt Cr., and Morrell Cr. drainages. No tree mortality was reported. (H.W. GODFREY, D.R., 11/21/46) (*U270*)
	1947	Seeley Lake	75,000*	DF,ES,SF,LPP	Same as in 1946. (H.W. GODFREY, D.R., 11/26/47) (*U270*)
	1948	Bonita	NR	DF	In the Harvey Cr., Eightmile, and N.Fk. Willow Cr. drainages, but without severe defoliation. (A.B. GUNDERSON, Acting For. Supv. 11/12/48) (*U270*)
		Seeley Lake	75,000*	DF,ES,SF,LPP	Same as in 1946. (H.W. GODFREY, D.R., 11/1/48) (*U270*)
	1949	Bonita	NR	DF	Subsided in the Harvey Cr. drainage, but newly observed in Rock Cr. (E.H. MYRICK, For. Supv., memorandum to the Regional Forester, 12/1/49) (*U270*)
		Seeley Lake	80,000	DF,ES,SF,LPP	Endemic, with few host trees defoliated. (H.W. GODFREY, D.R., 11/21/49) (*U270*)
	1950	Bonita	NR	DF	Host trees were considerably defoliated in parts of the Harvey Cr., Rock Cr., and N.Fk. Willow Cr. drainages. (W.K. SAMSELL, D.R., 11/16/50) (*U270*)
		Seeley Lake	80,000*	DF	Endemic, with host trees only lightly defoliated and none killed in the same areas reported as infested in 1946. (H.W. GODFREY, D.R., by H.C. ROWLAND, 11/9/50) (*U270*)
	1951	Bonita	25,000	DF	Moving westward, now in the Tyler Cr. drainage (1950-infested areas presumably infested in 1951.--Authors). (W.K. SAMSELL, D.R., 10/16/51) (*U270*)
		Seeley Lake	NR	WL,DF,ES,SF	Same as in 1950, endemic or with a decreasing trend. (H.W. GODFREY, D.R., 10/10/51) (*U270*)

[1]Parenthesized names are those of former National Forests now part of the named Forest.

[2]Parenthesized names are those of former Ranger Districts now part of the named District.

[3]NR, not reported. Acreages followed by an asterisk (*) were outlined on maps that accompanied the report.

[4]Abbreviations for names of host tree species:

DF	Douglas-fir	LPP	Lodgepole pine
GF	Grand fir	PP	Ponderosa pine
SF	Subalpine fir	WWP	Western white pine
ES	Engelmann spruce	WH	Western hemlock
WL	Western larch	WR	Western redcedar

[5]Italicized statements are considered significant observations of the budworm's biology or behavior.

able 5.--*Infestations by the western spruce budworm reported in Glacier and Yellowstone National Parks, 1922 through 1964*

ational ark	Year	Ranger district	Infested acreage[1]	Host tree species[2]	Pertinent infestation conditions, reporter, and references[3]
					MONTANA
lacier	1946	Hudson Bay	NR	ES	In the Waterton R. (T.37N.,R.18W.) and Belly R. (T.36N., R.17W.) drainages. (R.E. DENTON, Entomologist, Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, Feb. 1952 (*U44*)
		West Lakes	NR	ES	In the Nyack Cr. and Thompson Cr. drainages (T.32N.,R.16W.) (R.E. DENTON, Feb. 1952) (*U44*)
	1947	Hudson Bay	NR	ES	A peak in the infestation was reached this year in the Waterton R. and Belly R. drainages. (R.E. DENTON, Feb. 1952) (*U44*)
		West Lakes	NR	ES	The epidemic reached its peak intensity in the Nyack Cr. and Thompson Cr. drainages. (R.E. DENTON, Feb. 1952) (*U44*)
	1948	West Lakes	8,500	ES	An assessment of cumulative host tree damage from continued defoliation from 1946 to 1948 revealed that it was light in the lower part of the Nyack Cr. drainage, moderate to severe in the middle and upper parts of the drainage, and very severe--100% host tree mortality on 1,000 acres--in the Thompson Cr. drainage. *The infestations in the two drainages during the period were among the most severe of those in the northern Rocky Mts. as well as being unique because the host was solely ES.* (R.E. DENTON, Feb. 1952) (*U44*)
	1950	West Lakes	NR	ES	Host trees in the Nyack Cr. basin were only lightly defoliated. (P.C. JOHNSON, Entomologist, Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, 10/13/50) (*U110*)
	1951	West Lakes	NR	ES	No detailed description. (R.E. DENTON, Feb. 1952)(*U44*)
	1952	West Lakes	NR	ES	Declined; presumably terminated. (R.E. DENTON, Feb. 1952) (*U44*)
					WYOMING, MONTANA, AND IDAHO
llowstone	1922	North	NR	NR	*Believed to have been first noticed in the Blacktail Deer Cr. basin, Wyoming, in this year.* (J.C. EVENDEN, Entomologist, Bur. Entomol., Coeur 'Alene, Idaho, 10/5/23) (*U61*)
	1923		NR	DF,ES	Currently defoliated host trees--primarily DF--were evident from Mammoth Hot Springs to Tower Fall, in the Yellowstone R. canyon and side drainages from Blacktail Deer Cr. to Garnet and Crescent Hills, and in the Lamar R. canyon. Approximately 8% of the host trees were dead from budworm feeding (presumably in years prior to 1923--Authors). (J.C. EVENDEN, 10/5/23) (*U61*)
	1924	North	NR	DF,ES	The severity of host tree damage materially increased (presumably in the 1923-infested areas--Authors). Fifty percent of the infested DF trees were estimated to have been killed in the general area of the outbreak (see authors' comments in the 1923 report above--Authors). Defoliation was the most severe in pure stands of DF. *Thousands of DF trees weakened by budworm-caused defoliation were being attacked by the Douglas-fir beetle.* (J.C. EVENDEN, 10/2?/24) (*U62*)
	1925	North	NR	DF,ES	No noticeable defoliation and no budworm eggs or young caterpillars were found in September 1925 in areas infested in 1923 and 1924. Many DF trees under 6 inches d.b.h. were dead from cumulative defoliation in previous years, while DF trees from 6 to 10 inches survived the defoliation and either resisted the first attacks of the Douglas-fir beetle or were not attractive hosts for the beetle. DF trees over 10 inches d.b.h. survived the defoliation very well but were attacked and killed by the beetle. (H.E. BURKE, Entomologist, Bur. Entomol., Stanford Univ., Calif., 3/16/26) (*U19*)

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Table 5. (con.)

National Park	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Yellowstone	1951	North	3,000	DF	In Reese Cr. and upper Stephens (Stevens) Cr. (T.9S.,R.8E., Prin. Mer. Mont.); very heavy defoliation of 1951 needles. Heavy budworm populations in August 1951 in vicinity of Mammoth Hot Springs, with night flying moths seen from there to Cooke City. (R.E. DENTON, Entomol., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, Feb. 1952) (*U44*)
	1952	North	15,720	DF	Electric Peak (Reese Cr., Stephens Cr.), 6,220 acres; Undine Falls, 2,330 acres; and Yellowstone R. (probably from Park boundary to Garnet Hill), 7,170 acres. Light defoliation in all areas. (R.E. DENTON, Entomol., Bur. Entomol. and Plant Quar., Coeur d'Alene, Idaho, 11/6/52) (*U45*)
	1953	North	22,000		Electric Peak-Sepulcher Mt., 6,800 acres; Yellowstone R., 15,200 acres. Defoliation light, 8,200 acres; moderate, 8,400 acres; and heavy, 5,400 acres. (R.E. DENTON, Entomol., For. Serv., Intermt. For. and Range Exp. Stn., Coeur d'Alene, Idaho, 6/3/54) (*U49*)
	1954	North	55,410*	DF	No report, acreage estimate derived from 1955 report, below.
	1955	North	60,840*	DF	Total of 55,410 acres of infested DF forest type aerially sprayed with DDT in July 1955 from northwest corner of Park throughout Yellowstone R. drainage to Tower Fall and Lamar Canyon. Scattered new light infestations totaling 5,430 acres near Druid Peak and Coyote Cr. (T.T. TERRELL, Entomol., For. Serv., Intermt. For. and Range Exp. Stn., Missoula, Mont., 1/11/56) (*U216*)
	1956	North	71,680*	DF	Defoliation averaged 10 percent on 55,410 acres of infested DF type aerially sprayed in July 1955. New infestations totaling 38,910 acres of DF type suffered moderate to heavy defoliation (mostly in Slough Cr., Soda Butte Cr., middle Lamar R., and Grand Canyon of the Yellowstone R.). (P.C. JOHNSON, Entomol., For. Serv., Intermt. For. and Range Exp. Stn., Missoula, Mont., 1/21/57) (*U118*)
	1957	North	71,680*	DF	Infested DF forest type totaling 67,800 acres aerially sprayed with DDT in Slough Cr., Soda Butte Cr., Lamar R., and Grand Canyon of the Yellowstone R.; also 3,880 acres in 1955-controlled unit to the west. Remainder of infested acreage lightly defoliated. (Files of the PEST CONTROL SECTION, Northern Region, For. Serv., Missoula, Mont.; T.T. TERRELL, Entomol., For. Serv., Intermt. For. and Range Exp. Stn., Missoula, 6/6/57; D. McCOMB and T.T. TERRELL, Entomols., For. Serv., Intermt. For. and Range Exp. Stn., Missoula, March 1958) (*U118,U181*)
	1958	North	71,680*	DF	Still evident throughout all previously infested areas. Heavy foliage discoloration from the spruce spider mite, *Oligonychus ununguis* (Jacobi), superimposed over that from budworm feeding in the drainages of Electric Cr., Reese Cr., and Stephens Cr. aerially sprayed with DDT in 1955 and those of Slough Cr., Soda Butte Cr., and Lamar R. sprayed with DDT in 1957. (T.T. TERRELL and D.G. FELLIN, Entomols., For. Serv., Intermt. For. and Range Exp. Stn., Missoula, March 1959) (*U237*)
	1959	North	71,680*	DF	Defoliation in 1959 at five sampling locations: 64, 55, 1, 0, 0 percent. (T.T. TERRELL, R.E. DENTON, and D.G. FELLIN, Entomols., For. Serv., Intermt. For. and Range Exp. Stn., Missoula, Mont., Jan. 1960) (*U235*)
	1960	North	71,680	DF	No details. (T.T. TERRELL, Entomol., For. Serv., Intermt. For. and Range Exp. Stn., Missoula, Mont., Feb. 1961)(*U223*)
	1961	North	10,750*	DF	Light over 98 percent of infested areas on Sepulcher Mt. and in Slough Cr., Soda Butte Cr., and Lamar R. drainages. (T.T. TERRELL, Entomol., For. Serv., Northern Region, Missoula, Mont., Apr. 1962) (*U226*)
	1962	North	5,940*	DF	All areas lightly defoliated; infested areas generally located as in 1961. (T.T. TERRELL, Entomol., For. Serv., Northern Region, Missoula, Mont., Jan. 1968) (*U225*)

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'able 5. (con.)

ational ark	Year	Ranger district	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
ellowstone	1963	North	1,050*	DF	Light or moderate defoliation in W.Fk. Electric Cr. and Chalcedony Cr. (T.T. TERRELL and K.W. KEEFE, Entomols., For. Serv., Northern Region, Missoula, Mont., Feb. 1964) (*U240*)
	1964	North	3,310*	DF	Mostly light defoliation, Electric Cr. and Sepulcher Mt. (T.T. TERRELL and K.W. KEEFE, Entomols., For. Serv., Northern Region, Missoula, Mont., Jan. 1965) (*U241*)

[1]NR, not reported. Acreages followed by an asterisk (*) were outlined on maps that accompanied the report.

[2]DF, Douglas-fir; SF, subalpine fir; ES, Engelmann spruce.

[3]Host tree species abbreviated as in column 5. Italicized statements are considered significant observations f the budworm's biology or behavior.

Table 6.--*Infestations by the western spruce budworm reported in National Forests of the Intermountain Region, 1922 through 1953*

National Forest[1]	Year	Infested acreage[2]	Host tree species[3]	Pertinent infestation conditions, reporter, and references
				IDAHO
Boise[4]	1922	NR	DF,GF,ES,WL	Defoliation very common throughout the Forest. (J.C. EVENDEN, Entomologist, U.S. Dep. Agric., Bur. Entomol., Coeur d'Alene, Idaho, 10/28/22) (*U59*)
	1923	NR	ES,DF,GF	Considerable defoliation but little mortality of named host trees. (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 11/3/23[5]) (*U189*)
	1924	NR	NR	Defoliation appears to be decreasing. (R.H. RUTLEDGE, (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., Oct. 1924[5]) (*U189*)
	1927	NR	SF,GF,DF	"The budworm is killing a lot of alpine fir, white fir, and in places considerable Douglas-fir." (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 11/29/27[5]) (*U189*)
	1929	NR	NR	"...less active this year and appears to be subsiding." (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 10/26/29[5]) (*U189*)
	1930	NR	NR	"The spruce budworm epidemic is apparently at an end." (R.H. RUTLEDGE, Regional Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 10/8/30[5]) (*U200*)
	1931	NR	NR	Defoliation at a very low (endemic) stage. (R.H. RUTLEDGE, Regional Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 12/2/31[5]) (*U201*)
	1950	NR	DF,GF,SF, ES,LPP	Moderate defoliation of DF in the Deadwood R. drainage; a budworm similar to the spruce budworm caused fairly heavy defoliation in LPP stands in the eastern part of the Forest. (L.W. ORR, Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Ogden, Utah, March 1951) (*U185*)
	1951	NR	DF,SF	Moderate to severe defoliation in host stands in the Deadwood R., Beaver Cr., Lost Cr., Banner Cr., and Clear Cr. drainages. (L.W. ORR, Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Ogden, Utah, Feb. 1952) (*U186*)
	1952	NR	DF,GF,SF,ES	Defoliation in host stands increased in severity and extent in the eastern half of the Forest; practically all new foliage of host trees was destroyed south and west of Atlanta, and in the Beaver Cr. and Deadwood R. drainages. (L.W. ORR, Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Ogden, Utah, 9/9/52) (*U187*)
	1953	NR	DF,GF,SF,ES	Moderate to severe defoliation from smaller but better surviving larval populations; still no extensive killing of host stands, but many intermediate and suppressed host trees are dying or dead. (L.W. ORR, Entomologist, Intermt. For. and Range Exp. Stn., Ogden, Utah, April 1954) (*U188*)
Challis (Lemhi)	1923	NR	ES,DF,GF	Approaching epidemic status in the Lost Cr., Stanley Basin, and Cape Horn country. (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 11/3/23[5]) (*U189*)
	1924	NR	NR	Lost Cr. (*U189*)
	1937	NR	ES	Prevalent in most host stands; very little defoliation and host tree growth is not retarded. (E.E. McKEE, FOREST Supv., Challis-Lemhi Natl. For., Challis, Idaho, 10/15/37) (*U189,U254*)
Payette[6] (Weiser, Idaho)	1922	NR	DF,GF,ES,WL	Defoliation observed in N.Fk. Payette R. and upper Little Salmon R. drainages.(J.C. EVENDEN, Entomologist, U.S. Dep. Agric., Bur. Entomol., Coeur d'Alene, Idaho, 10/28/22) (*U59, 35*)
	1923	NR	ES,DF,GF	Considerable defoliation but no mortality of host trees. (R.H. RUTLEDGE District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 11/3/23[5]) (*U189*)

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able 6. (con.)

ational orest	Year	Infested acreage	Ho t tree species	Pertinent infestation conditions, reporter, and references
ayette[6] Weiser, Idaho	1924	NR	NR	Defoliation appears to be decreasing. (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., Oct. 1924[5]) (*U189*)
	1927	NR	SF,GF,DF	"The budworm is killing a lot of alpine fir, white fir, and in places considerable Douglas-fir." (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 11/29/27[5])(*U189*)
	1928	NR	GF,SF,DF	Much defoliation throughout host types on Ranger District #1 and in the Goodrich Cr., Dukes Cr., and Johnson Cr. drainages of Ranger District #2 (Weiser Natl. For.). In the latter District, GF has been entirely killed (GF stands?--Authors) and considerable DF has been seriously damaged. Pure stands of GF and DF will be wiped out unless the budworm is checked. (J. RAPHAEL, Forest Supv., Weiser Natl. For., McCall, Idaho, 10/15/28) (*U251*)
	1929	NR	DF,ES,GF,SF	Infestations appear to have subsided to current endemic status, but past infestations have completely defoliated some of the smaller GF and SF trees. Most of the trees damaged by past defoliation are recuperating. (S.C. SCRIBNER, Forest Supv., Idaho Natl. For., McCall, Idaho, 10/12/29) (*U252*) Defoliation continued in some localities; epidemic infestation probably exists in parts of the Bear R. Ranger District (Weiser Natl. For.), but infestations are less prevalent than those of several years ago over most of the Forest. (J. RAPHAEL, Forest Supv., Weiser Natl. For., Weiser, Idaho, 10/14/29) (*U251*)
	1930	NR	NR	Reported "still going." (*U189*)
ayette	1952	NR	DF,GF,SF,ES	Heavy defoliation near Riggins, with this area and infested areas on the Boise National Forest totaling 1 million acres of host forests. (L.W. ORR, Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Ogden, Utah, 9/9/52) (*U187*)
	1953	NR	DF,GF,SF,ES	Moderate to severe defoliation (totaling 1/2 million acres of host forests on the Boise, Payette, and Salmon National Forests) with no extensive killing of host stands but with many intermediate and suppressed host trees dying or dead. The most severe host stand damage was observed in the Big Cr. drainage of the Idaho Primitive Area. Many infested stands on the Forest contain a high proportion of good quality grand fir. (L.W. ORR, Entomologist, Intermt. For. and Range Exp. Stn., Ogden, Utah, April 1954) (*U188*)
lmon	1953	NR	DF,GF,SF,ES	Moderate to severe defoliation (totaling 1/2 million acres of host forests on the Boise, Payette, and Salmon National Forests) with no extensive killing of host stands but with many intermediate and suppressed host trees dying or dead. The most severe host stand damage was observed in the Big Cr. drainage of the Idaho Primitive Area. Many infested stands on the Forest contain a high proportion of good quality grand fir. (L.W. ORR, Entomologist, Intermt. For. and Range Exp. Stn., Ogden, Utah, April 1954) (*U188*)
wtooth	1924	NR	NR	No detailed information. (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., Oct. 1924[5]) (*U189*)
	1927	NR	DF,SF	No detailed information. (*U189*)
	1930	NR	NR	"The spruce budworm epidemic is apparently at an end" in the National Forests of western Idaho (Boise, Challis, Idaho (new Payette), Lemhi (Challis, Salmon), old Payette (Boise), Salmon, Sawtooth, and Weiser (new Payette)). (R.H. RUTLEDGE, Regional Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 10/8/30[5]) (*U189*)
	1949	NR	DF,ES	Severe defoliation near Big Smoky Ranger Station. (*U189*)
	1950	NR	DF	Moderate defoliation in the Little Smoky Cr. drainage. (L.W. ORR, Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Ogden, Utah, March 1951) (*U185*)

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Table 6. (con.)

National Forest	Year	Infested acreage	Host tree species	Pertinent infestation conditions, reporter, and references
Sawtooth	1951	NR	DF,SF	Defoliation much less severe than in 1950 in the Little Smoky Cr. drainage. (L.W. ORR, Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Ogden, Utah, Feb. 1952) (*U186*)
	1952	NR	DF,SF,ES	Defoliation much reduced over that of the past two years. (L.W. ORR, Entomologist, U.S. Dep. Agric., Bur. Entomol. and Plant Quar., Ogden, Utah, 9/9/52) (*U187*)
	1953	NR	DF,SF,ES	Smaller but better surviving budworm populations noted in infested areas (L.W. ORR, Entomologist, Intermt. For. and Range Exp. Stn., Ogden, Utah, April 1954) (*U188*)
Targhee	1927	NR	NR	Infestation reported; no details. (*U189*)
	1943	NR	NR	Infestation reported; no details. (*U189*)
	1944	NR	NR	Infestation reported; no details. (*U189*)
				WYOMING
Bridger (Wyoming)	1926	NR	SF,DF	Defoliation reported, no details. (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 12/13/26[5]) (*U189*)
	1935	NR	NR	Small area on Greys R. infested. (R.H. RUTLEDGE, Regional Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 11/9/35[5])(*U189*)
Teton	1923	NR	NR	Infestation reported; no details. (*U189*)
	1924	NR	NR	Heavy defoliation, no details.(R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., Oct. 1924[5]) (*U189*)
				UTAH
Cache	1927	NR	LPP	Budworm infesting LPP trees in Emigrant Cr. and Williams Cr. drainages (not substantiated--Authors). (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., 11/29/27[5]) (*U189*)
Uinta	1924	NR	NR	"Considerable spruce budworm." (R.H. RUTLEDGE, District (Regional) Forester, Ogden, Utah; letter to Chief Forester, Washington, D.C., Oct. 1924[5]) (*U189*)
	1925	15	LPP	In the Duchesne R. drainage. (*U189*)
Wasatch	1929	NR	SF	Defoliation of host trees near Timpanogos Cave. (*U189*)
				NEVADA
Humbolt	1931	NR	NR	Infestation reported; no details. (*U189*)
(Nevada)	1935	NR	NR	Infestation reported; no details. (*U189*)

[1]Parenthesized names are those of former National Forests now part of the named Forest.
[2]NR, not reported.
[3]Host tree species abbreviations:

DF	Douglas-fir	ES	Engelmann spruce
GF	Grand fir	WL	Western larch
SF	Subalpine fir	LPP	Lodgepole pine

[4]Includes the original Payette National Forest combined with the Boise National Forest on April 1, 1944.
[5]Permanently filed at the Federal Records Center, Denver, Colorado; for retrieval contact the Division of Timber Management, Forest Service, Federal Building, Ogden, Utah 84401.
[6]Present Payette National Forest created April 1, 1944, by consolidation of the former Idaho and Weiser National Forests.

Table 7.--*Estimated gross acreage of host forests visibly defoliated by the western spruce budworm within the Northern Region, by States, 1948 through 1971*

Year	Administrative unit[1]	Wash.	Idaho	Mont.	Total	References
1948	Glacier Natl. Park			8,500		
	Helena N.F.			261,560	270,060	*U107*
	Totals			270,060	270,060	
1949	Deerlodge N.F.			90,000		*U108*
	Helena N.F.			290,000		*U108*
	Gallatin N.F.			26,000		*U108*
	Nezperce N.F.		25,280			*U101*
	Totals		25,280	406,000	431,280	
1950	Clearwater N.F.		10,600			*U41*
	Deerlodge N.F.			100,000		*U109*
	Flathead N.F.			218,000		*U39,U40*
	Gallatin N.F.			26,000		*U93*
	Helena N.F.			290,000		*U93,U111*
	Lewis & Clark N.F.			50,000		*U93*
	Nezperce N.F.		12,480			*U38*
	Craig Mt. (private)		7,080			*U38*
	Glacier Natl. Park			5,000		*U93,U110*
	Totals		30,160	689,000	719,160	
1951	Bitterroot N.F.			12,000		*U44,U110*
	Clearwater N.F.		23,700			*U44,U45*
	Deerlodge N.F.			120,000		*U44,U114*
	Flathead N.F.			235,000		*U44,U45, U114*
	Gallatin N.F.			80,000		*U44,U45, U114*
	Helena N.F.			560,000		*U44,U45, U114*
	Lewis & Clark N.F.			100,000		*U44,U45, U114*
	Lolo N.F.			1,600		*U44,U45, U114*
	Nezperce N.F.		20,500			*U44,U45*
	Craig Mt. (private)		9,200			*U44,U45, U114*
	Garnet Range (BLM)			30,000		*U45*
	Glacier Natl. Park			1,000		*U44,U45, U112,U114*
	Yellowstone Natl. Park			[2] 3,000		*U44,U45, U114*
	Totals		53,400	1,142,600	1,196,000	

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Table 7. (con.)

Year	Administrative unit	Wash.	Idaho	Mont.	Total	References
1952	Beaverhead N.F.			17,560		*U45*
	Bitterroot N.F.			123,140		*U45*
	Clearwater N.F.		80,380			*U45*
	Deerlodge N.F.			297,480		*U45*
	Flathead N.F.			23,320		*U45*
	Gallatin N.F.			180,080		*U45*
	Helena N.F.			583,040		*U45*
	Lewis & Clark N.F.			194,790		*U45*
	Lolo N.F.			47,360		*U45*
	Nezperce N.F.		58,620			*U45*
	Craig Mt. (private)		129,440			*U45*
	Garnet Range (BLM)			162,120		*U45*
	Yellowstone Natl. Park			[2]15,720		*U45*
	Totals		268,440	1,644,610	1,913,050	
1953	Beaverhead N.F.			31,600		*U47*
	Bitterroot N.F.			140,300		*U47*
	Clearwater N.F.		80,400			*U47*
	Deerlodge N.F.			269,600		*U47*
	Flathead N.F.			59,900		*U47*
	Gallatin N.F.			304,500		*U47*
	Helena N.F.			565,500		*U47*
	Lewis & Clark N.F.			202,400		*U47*
	Lolo N.F.			48,400		*U47*
	Nezperce N.F.		42,600			*U47*
	Craig Mt. (private)		138,400			*U47*
	Garnet Range (BLM)			195,100		*U47*
	Yellowstone Natl. Park			[2]22,000		*U47*
	Totals		261,400	1,839,300	2,100,700	
1954	Beaverhead N.F.			110,850		*U3*
	Bitterroot N.F.			126,020		*U3*
	Clearwater N.F.		86,700			*U3*
	Deerlodge N.F.			278,000		*U3*
	Flathead N.F.			60,050		*U3*
	Gallatin N.F.			379,900		*U3*
	Helena N.F.			680,250		*U3*
	Lewis & Clark N.F.			66,600		*U3*
	Lolo N.F.			59,480		*U3*
	Nezperce N.F.		38,880			*U3*
	Craig Mt. (private)		171,500			*U3*
	Garnet Range (BLM)			126,100		*U3*
	Yellowstone Natl. Park			[2]55,410		*U216*
	Totals		297,080	1,942,660	2,239,740	

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ble 7. (con.)

ar	Administrative unit	Wash.	Idaho	Mont.	Total	References
55	Beaverhead N.F.			372,890		*U180,U217*
	Bitterroot N.F.			179,510		*U180*
	Clearwater N.F.		101,910			*U180,U217*
	Deerlodge N.F.			490,470		*U180,U217*
	Flathead N.F.			870		*U180,U217*
	Gallatin N.F.			579,670		*U180*
	Helena N.F.			842,260		*U180,U217*
	Lewis & Clark N.F.			408,420		*U180,U217*
	Lolo N.F.			89,220		*U180,U217*
	Nezperce N.F.		70,790			*U180*
	Craig Mt. (private)		89,480			*U180,U217*
	Garnet Range (BLM)			186,320		*U180,U217*
	Yellowstone Natl. Park			[2]60,840		*U180*
	Totals		262,180	3,210,470	3,472,650	
56	Beaverhead N.F.			506,140		*U180*
	Bitterroot N.F			298,200		*U180*
	Clearwater N.F.		119,370			*U180*
	Deerlodge N.F.			535,200		*U180*
	Flathead N.F.			2,500		*U180*
	Gallatin N.F.			936,700		*U180*
	Helena N.F.			900,430		*U180*
	Lewis & Clark N.F.			535,510		*U180*
	Lolo N.F.			69,800		*U180*
	Nezperce N.F.		83,700			*U180*
	Craig Mt. (private)		60,000			*U180*
	Garnet Range (BLM)			226,800		*U180*
	Yellowstone Natl. Park			[2]142,500		*U180*
	Totals		263,070	4,153,780	4,416,850	
57					[3]4,663,850	*U181*
58					[3]4,894,690	*U237*
59					[3]4,894,690	*U235*
60	Beaverhead N.F.			134,270		*U226*
	Bitterroot N.F.			281,160		*U226*
	Deerlodge N.F.			282,240		*U226*
	Gallatin N.F.			465,160		*U226*
	Helena N.F.			658,990		*U226*
	Lewis & Clark N.F.			464,040		*U226*
	Lolo N.F.			40,420		*U226*
	Craig Mt. (private)		89,480			*U226*
	Garnet Range (BLM)			203,610		*U226*
	Yellowstone Natl. Park			[2]10,750		*U226*
	Totals		89,480	2,540,640	2,630,120	

(con. next page; for footnotes see end of table)

Table 7. (con.)

Year	Administrative unit	Wash.	Idaho	Mont.	Total	Reference
1961	Beaverhead N.F.			85,440		U228
	Bitterroot N.F.			276,870		U228
	Deerlodge N.F.			305,870		U228
	Gallatin N.F.			411,960		U228
	Helena N.F.			752,140		U228
	Lewis & Clark N.F.			576,450		U228
	Lolo N.F.			136,880		U228
	Centennial Val. (BLM)			24,700		U228
	Craig Mt. (private)		3,220			U228
	Garnet Range (BLM)			238,090		U228
	Yellowstone Natl. Park			[2] 9,500		U228
	Totals		3,220	2,817,900	2,821,120	
1962	Beaverhead N.F.			55,600		U228
	Bitterroot N.F.			324,830		U228
	Deerlodge N.F.			308,180		U228
	Gallatin N.F.			385,440		U228
	Helena N.F.			831,610		U228
	Lewis & Clark N.F.			527,090		U228
	Lolo N.F.			171,590		U228
	Centennial Val. (BLM)			27,890		U228
	Craig Mt. (private)		1,030			U228
	Garnet Range (BLM)			256,760		U228
	Yellowstone Natl. Park			[2] 5,940		U228
	Totals		1,030	2,894,930	2,895,960	
1963	Beaverhead N.F.			70,250		U240
	Bitterroot N.F.		105,530	246,240		U240
	Custer N.F.			710		U240
	Deerlodge N.F.			158,650		U240
	Gallatin N.F.			291,290		U240
	Helena N.F.			441,170		U240
	Kaniksu N.F.	[4] 10,200	940			U240
	Lewis & Clark N.F.			317,230		U240
	Lolo N.F.			125,880		U240
	Nezperce N.F.		6,500			U240
	Centennial Val. (BLM)			18,640		U240
	Craig Mt. (private)		1,700			U240
	Garnet Range (BLM)			225,320		U240
	Judith Mts. (BLM)			580		U240
	Yellowstone Natl. Park			[2] 1,050		U240
	Totals	10,200	114,670	1,897,010	2,021,880	

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able 7. (con.)

ear	Administrative unit	Wash.	Idaho	Mont.	Total	References
964	Beaverhead N.F.			116,260		U241
	Bitterroot N.F.		98,810	148,220		U241
	Colville N.F.	[4] 740				U241
	Custer N.F.			3,720		U241
	Deerlodge N.F.			99,310		U241
	Gallatin N.F.			254,380		U241
	Helena N.F.			546,780		U241
	Kaniksu N.F.	[4] 2,060				U241
	Lewis & Clark N.F.			389,450		U241
	Lolo N.F.			151,790		U241
	Nezperce N.F.		166,610			U241
	Centennial Val. (BLM)			14,170		U241
	Craig Mt. (private)		2,680			U241
	Garnet Range (BLM)			190,320		U241
	Judith Mts. (BLM)			3,780		U241
	Yellowstone Natl. Park			[2] 3,310		U241
	Totals	2,800	268,100	1,921,490	2,192,390	
965	Beaverhead N.F.			87,520		Compiled[5]
	Bitterroot N.F.		166,400	300,000		do.
	Deerlodge N.F.			47,760		do.
	Helena N.F.			546,780		do.
	Gallatin N.F.			468,480		do.
	Lewis & Clark N.F.			617,270		do.
	Lolo N.F.			507,060		do.
	Nezperce N.F.		566,350			do.
	Judith Mts. (BLM)			4,020		do.
	Yellowstone Natl. Park			[2] 2,560		do.
	Totals		732,750	2,581,450	3,314,200	
966	Beaverhead N.F.			51,660		Compiled[5]
	Bitterroot N.F.		219,150			do.
	Clearwater N.F.		33,870			do.
	Custer N.F.			9,170		do.
	Deerlodge N.F.			22,180		do.
	Helena N.F.			316,080		do.
	Lolo N.F.			345,320		do.
	Nezperce N.F.		571,400			do.
	Judith Mts. (BLM)			6,160		do.
	Sweetwater Hills (BLM)			44,560		do.
	Totals		824,420	795,130	1,619,550	

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Table 7. (con.)

Year	Administrative unit	Wash.	Idaho	Mont.	Total	References
1967	Beaverhead N.F.			19,360		Compiled[5]
	Bitterroot N.F.		23,120	180,770		do.
	Clearwater N.F.		127,250			do.
	Custer N.F.			6,080		do.
	Deerlodge N.F.			430		do.
	Flathead N.F.			5,390		do.
	Gallatin N.F.			54,820		do.
	Helena N.F.			316,080		do.
	Lewis & Clark N.F.			32,230		do.
	Lolo N.F.			1,142,020		do.
	Nezperce N.F.		592,020			do.
	Judith Mts. (BLM)			5,430		do.
	Yellowstone Natl. Park			[2]12,700		do.
	Totals		742,390	1,775,310	2,517,700	
1968	Beaverhead N.F.			11,500		*56*
	Bitterroot N.F.		152,820	242,080		*56*
	Clearwater N.F.		240,600			*56*
	Custer N.F.			50,400		*56*
	Deerlodge N.F.			58,800		*56*
	Flathead N.F.			27,760		*56*
	Gallatin N.F.			187,300		*56*
	Helena N.F.			465,960		*56*
	Lewis & Clark N.F.			157,100		*56*
	Lolo N.F.			1,419,710		*56*
	Nezperce N.F.		1,310,100			*56*
	Flathead Indian Res.			59,240		*56*
	Garnet Range (BLM)			164,460		*56*
	Judith Mts. (BLM)			7,910		*56*
	Yellowstone Natl. Park			[2]22,700		*56*
	Totals		1,703,520	2,874,920	4,578,440	
1969	Beaverhead N.F.			20,170		Computed[5]
	Bitterroot N.F.		162,500	221,170		do.
	Clearwater N.F.		294,140			do.
	Custer N.F.			11,310		do.
	Deerlodge N.F.			96,230		do.
	Flathead N.F.			119,370		do.
	Gallatin N.F.			58,750		do.
	Helena N.F.			374,530		do.
	Lewis & Clark N.F.			75,340		do.
	Lolo N.F.			1,554,560		do.
	Nezperce N.F.		1,008,380			do.
	St. Joe N.F.		15,510			do.
	Yellowstone Natl. Park			[2] 5,610		do.
	Totals		1,480,530	2,537,040	4,017,570	

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ıble 7 (con.)

ear	Administrative unit	Wash.	Idaho	Mont.	Total	References
·970	Bitterroot N.F.		162,500	302,500		Computed[5]
	Clearwater N.F.		360,000			do.
	Deerlodge N.F.			204,800		do.
	Flathead N.F.			61,500		do.
	Helena N.F.			32,000		do.
	Lolo N.F.			1,042,000		do.
	Nezperce N.F.		1,300,000			do.
	St. Joe N.F.		28,000			do.
	Flathead Indian Res.			163,000		do.
	Yellowstone Natl. Park			[2] 2,000		do.
	Totals		1,850,500	1,807,800	3,658,300	
·971	Beaverhead N.F.			15,000		Computed[5]
	Bitterroot N.F.		2,500	172,500		21
	Clearwater N.F.		378,000			21
	Deerlodge N.F.			285,680		21
	Flathead N.F.			167,000		21
	Gallatin N.F.			15,260		21
	Helena N.F.			377,280		21
	Lolo N.F.			1,260,000		21
	Nezperce N.F.		1,337,000			21
	St. Joe N.F.		42,560			21
	Flathead Indian Res.			194,000		21
	Yellowstone Natl. Park			[2]46,080		21
	Totals		1,760,060	2,532,800	4,292,860	

[1]Includes lands of all ownerships within or adjacent to the unit.
[2]Includes some lands in Wyoming and Idaho.
[3]Regional acreage not itemized by States.
[4]Biological evaluation made and reported by the Pacific Northwest Region (Region 6), SDA Forest Service, Portland, Oregon.
[5]Compiled by the Intermountain Forest and Range Experiment Station from original ırvey maps furnished by the Northern Region.

Table 8.--*Estimated gross acreage of host forests visibly defoliated by the western spruce budworm within the Intermountain Region, by States, 1954 through 1971*[1]

Year	National Forest[2]	Idaho	Wyoming	Utah	Total	References
1954	Boise	514,000				*U99,U100*
	Payette	114,000				*U99,U101*
	Boise-Payette	372,000[3]				*U100*
	Totals	1,000,000			1,000,000	
1955	Boise	681,000				*U24,U100*
	Challis	8,000				*U24*
	Payette	358,000				*U24,U100*
	Salmon	128,000				*U24*
	Totals	1,175,000			1,175,000	
1956	Boise	308,970				*U25,U26*
	Challis	22,250				*U26*
	Payette	383,310				*U25,U26*
	Salmon	249,600				*U25,U26*
	Sawtooth	71,400				*U26*
	Targhee	92,010				*U25,U26*
	Totals	1,127,540			1,127,540	
1957	Boise	131,370				*U28*
	Challis	38,310				*U28*
	Payette	445,580				*U28*
	Salmon	340,010				*U28*
	Sawtooth	99,310				*U28*
	Targhee	118,360				*U28*
	Totals	1,172,940			1,172,940	
1958	Boise	33,700				*U29*
	Challis	103,500				*U29*
	Payette	14,850				*U29*
	Salmon	478,000				*U29*
	Sawtooth	140,300				*U29*
	Targhee	204,360				*U29*
	Totals	974,710			974,710	
1959	Payette	5,000				*U295*
	Salmon	165,000				*U295*
	Sawtooth	125,000				*U295*
	Targhee	204,000				*U295*
	Totals	499,000			499,000	

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le 8. (con.)

r	National Forest	Idaho	Wyoming	Utah	Total	References
0	Challis	150,000				*U296*
	Salmon	115,000				*U296*
	Sawtooth	121,000				*U296*
	Targhee	130,500				*U296*
	Totals	516,500			516,500	
1	Boise	35,500				*U291*
	Challis	358,000				*U291*
	Payette	34,500				*U291*
	Salmon	858,000				*U291*
	Sawtooth	13,000				*U291*
	Targhee	126,000				*U291*
	Totals	1,425,000			1,425,000	
2	Boise	60,000				*U294*
	Challis	297,000				*U294*
	Payette	137,000				*U294*
	Salmon	929,000				*U294*
	Sawtooth	41,000				*U294*
	Targhee	177,000				*U294*
	Totals	1,641,000			1,641,000	
3	Boise	56,160				*U292*
	Challis	241,120				*U292*
	Payette	173,920				*U292*
	Salmon	877,180				*U292*
	Sawtooth	60,160				*U292*
	Targhee	214,560				*U292*
	Totals	1,623,100			1,623,100	
4	Boise	46,080[3]				*U293*
	Challis	619,460[3]				*U293*
	Fishlake			20,000		*U293*
	Payette	147,460[3]				*U293*
	Salmon	1,342,000				*U293*
	Sawtooth	54,000				*U293*
	Targhee	67,000[3]				*U293*
	Totals	2,276,000		20,000	2,296,000	

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Table 8. (con.)

Year	National Forest	Idaho	Wyoming	Utah	Total	References
1965	Boise	60,200				61
	Bridger		10,000			61
	Challis	401,300				61
	Fishlake			10,000		61
	Payette	216,800				61
	Salmon	709,900				61
	Sawtooth	9,000				61
	Targhee	97,900				61
	Totals	1,495,100	10,000	10,000	1,515,100	
1966	Boise	59,400				59
	Bridger		33,800			59
	Challis	169,100				59
	Payette	83,700				59
	Salmon	521,600				59
	Sawtooth	110,000				59
	Targhee	14,600				59
	Totals	958,400	33,800		992,200	
1967	Boise	28,900				60
	Bridger		51,800			60
	Caribou	100				60
	Challis	1,600				60
	Fishlake			100		60
	Payette	79,600				60
	Salmon	25,600				60
	Sawtooth	18,100				60
	Targhee	10,000				60
	Teton		2,900			60
	Totals	163,900	54,700	100	218,700	
1968	Ashley			400		2
	Boise	27,700				2
	Bridger		95.200			2
	Caribou	6,000				2
	Challis	33,300				2
	Payette	221,600				2
	Salmon	43,000				2
	Sawtooth	46,700				2
	Targhee	17,000				2
	Teton		14,600			2
	Totals	395,300	109,800	400	505,500	

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ble 8. (con.)

ar :	National Forest	Idaho	Wyoming	Utah	Total	References
69	Ashley			400		*62*
	Boise	31,000				*62*
	Bridger		72,800			*62*
	Caribou	500				*62*
	Challis	20,000				*62*
	Payette	362,200				*62*
	Salmon	47,700				*62*
	Targhee	1,800				*62*
	Teton		8,000			*62*
	Bryce Canyon Natl. Park			Reported		
	Totals	463,200	80,800	400	544,400	
70	Ashley			120		*79*
	Boise	5,800				*79*
	Bridger		55,800			*79*
	Caribou	100				*79*
	Payette	220,900				*79*
	Targhee	12,400				*79*
	Teton		12,600			*79*
	Totals	239,200	68,400	120	307,720	
71	Boise	17,200				*80*
	Bridger		25,200			*80*
	Caribou	100				*80*
	Payette	316,200				*80*
	Targhee	9,800				*80*
	Teton		5,400			*80*
	Totals	343,300	30,600		373,900	

[1]No data available prior to 1954.
[2]Includes lands of all ownerships within or adjacent to the National Forest.
[3]Estimated gross acreage of host forests lightly defoliated but not mapped.

ble 9.--*Numbers of references to host tree species in Ranger District reports*[1] *of outbreaks of western spruce budworm in National Forests in northern Idaho, Montana, 1925 through 1953*

Host species	Sole host in--		Host with other species in--	
	Idaho	Montana	Idaho	Montana
cky Mountain Douglas-fir	8	89	80	142
and fir	9	1	108	5
gelmann spruce	9	21	87	65
balpine fir	2	1	36	40
stern larch	1	0	8	4
stern white pine	0	0	2	0
dgepole pine	0	0	7	10
nderosa pine	0	0	1	0
mbers of reports	137	182	137	182

[1]Host tree species did not necessarily occur together in the same infested stands.

Table 10.--*National Forest Ranger Districts in northern Idaho reporting infestations of western spruce budworm, 1922 through 1953*

Year	National Forest	Ranger districts						
1922	Kaniksu	Priest Lake						
1923	Kaniksu	Priest Lake						
1924	Clearwater	Powell						
	Coeur d'Alene	Kingston						
	Kaniksu	Priest Lake						
	Nezperce	Red River						
1925	Clearwater	Powell						
	Nezperce	Clearwater	Red River					
1926	Bitterroot	Magruder						
	Clearwater	Lochsa	Powell					
	Nezperce	Clearwater	Elk City	Moose Creek	Red River	Salmon River	Selway	Slate Creek
1927	Bitterroot	Magruder						
	Clearwater	Lochsa	Pierce	Powell				
	Nezperce	Clearwater	Elk City	Moose Creek	Red River	Selway	Slate Creek	
	St. Joe	Avery						
1928	Clearwater	Lochsa	Pierce	Powell				
	Coeur d'Alene	Kingston						
	Nezperce	Clearwater	Elk City	Moose Creek	Red River	Selway	Slate Creek	
	St. Joe	Avery						
1929	Clearwater	Canyon	Lochsa	Powell				
	Coeur d'Alene	Kingston						
	Nezperce	Clearwater	Elk City	Moose Creek	Red River	Selway		
1930	Bitterroot	Magruder						
	Clearwater	Lochsa	Pierce					
	Coeur d'Alene	Kingston						
	Nezperce	Clearwater	Moose Creek	Red River	Selway			
1931	Bitterroot	Magruder						
	Clearwater	Lochsa						
	Coeur d'Alene	Kingston						
	Nezperce	Clearwater	Moose Creek	Red River	Selway			
1932	Clearwater	Bungalow	Lochsa					
	Coeur d'Alene	Kingston						
	Nezperce	Clearwater	Moose Creek	Selway				
1933	Clearwater	Bungalow	Lochsa					
	Coeur d'Alene	Kingston						
	Nezperce	Clearwater	Moose Creek	Selway				
1934	Bitterroot	Magruder						
	Clearwater	Lochsa						
	Nezperce	Moose Creek	Selway					
1935	Bitterroot	Magruder						
	Nezperce	Clearwater	Selway					
1936	Nezperce	Selway						
1937	Nezperce	Clearwater	Selway					
1938	Nezperce	Clearwater						
1939	Nezperce	Clearwater						
1940	Nezperce	Clearwater						
1941	Kaniksu	Trout Creek						
	Nezperce	Clearwater						
1942	Nezperce	Clearwater						
1943	Nezperce	Clearwater						
1944	None reported							
1945	Nezperce	Salmon River						
1946	Clearwater	Powell						
	Nezperce	Salmon River						
1947	Clearwater	Powell						
	Nezperce	Salmon River						
1948	Clearwater	Powell						
	Nezperce	Salmon River						
1949	Clearwater	Powell						
	Nezperce	Salmon River						
1950	Clearwater	Powell						
	Nezperce	Salmon River						
1951	Clearwater	Powell						
	Nezperce	Salmon River						
1952	Clearwater	Powell						
	Nezperce	Salmon River						
1953	Clearwater	Powell						
	Nezperce	Salmon River						

Table 11.--*National Forest Ranger Districts in Montana reporting infestations of western spruce budworm, 1925 through 1953*

Year	National Forest	Ranger districts		
1925	Beaverhead	Sheridan	Wisdom	
	Gallatin	Big Timber	Gardiner	Livingston
	Helena	Townsend		
1926	Beaverhead	Sheridan		
	Gallatin	Big Timber		
	Helena	Townsend		
1927	Beaverhead	Madison		
	Bitterroot	Stevensville		
	Gallatin	Bozeman	Livingston	
	Helena	Townsend		
1928	Beaverhead	Madison		
	Gallatin	Bozeman	Livingston	
	Helena	Townsend		
1929	Beaverhead	Madison		
	Gallatin	Livingston		
	Helena	Townsend		
1930	Gallatin	Livingston		
	Helena	Townsend		
	Lolo	Superior		
1931	Beaverhead	Madison	Sheridan	
	Gallatin	Livingston		
	Helena	Canyon Ferry	Townsend	
1932	Gallatin	Bozeman	Livingston	
	Helena	Canyon Ferry	Townsend	
	Lewis & Clark	Musselshell		
1933	Flathead	Coram		
	Gallatin	Bozeman	Livingston	
	Helena	Townsend		
	Lewis & Clark	Musselshell		
1934	Gallatin	Bozeman	Livingston	
	Helena	Townsend		
	Lewis & Clark	Musselshell		
1935	Custer	Beartooth		
	Gallatin	Bozeman	Livingston	
	Helena	Townsend		
	Lewis & Clark	Musselshell		
1936	Helena	Townsend		
1937	Custer	Beartooth		
	Gallatin	Bozeman	Livingston	
	Helena	Townsend		
	Lewis & Clark	Musselshell		
1938	Bitterroot	Stevensville	West Fork	
	Gallatin	Bozeman	Livingston	
	Helena	Townsend		
	Lewis & Clark	Musselshell		
	Lolo	Seeley Lake		
1939	Custer	Beartooth		
	Helena	Townsend		
	Kootenai	Fortine		
	Lolo	Seeley Lake		
1940	Custer	Beartooth		
	Helena	Townsend		
	Lolo	Seeley Lake		

(con. next page)

Table 11.--(con.)

Year	National Forest	Ranger districts			
1941	Beaverhead	Madison			
	Gallatin	Bozeman			
	Helena	Townsend			
	Lolo	Seeley Lake			
1942	Flathead	Spotted Bear			
	Gallatin	Bozeman	Hebgen Lake		
	Helena	Townsend			
1943	Flathead	Big Prairie	Spotted Bear		
	Gallatin	Bozeman			
	Helena	Townsend			
1944	Flathead	Big Prairie	Spotted Bear		
	Gallatin	Bozeman			
	Helena	Townsend			
	Lewis & Clark	White Sulphur			
1945	Deerlodge	Boulder	Whitehall		
	Flathead	Big Prairie	Spotted Bear		
	Gallatin	Bozeman			
	Helena	Canyon Ferry	Helena	Townsend	
	Lewis & Clark	White Sulphur			
1946	Deerlodge	Boulder	Whitehall		
	Flathead	Big Prairie	Coram	Swan Lake	
	Gallatin	Bozeman			
	Helena	Townsend			
	Lewis & Clark	Musselshell			
	Lolo	Seeley Lake			
1947	Deerlodge	Whitehall			
	Flathead	Big Prairie	Condon	Spotted Bear	
	Gallatin	Bozeman			
	Helena	Canyon Ferry	Helena	Townsend	
	Lewis & Clark	Belt Creek	Judith	Musselshell	White Sulphur
	Lolo	Seeley Lake			
1948	Deerlodge	Boulder	Whitehall		
	Flathead	Big Prairie	Condon	Spotted Bear	Swan Lake
	Gallatin	Bozeman			
	Helena	Canyon Ferry	Helena		
	Lewis & Clark	Musselshell			
	Lolo	Bonita	Seeley Lake		
1949	Beaverhead	Lima			
	Deerlodge	Boulder	Whitehall		
	Flathead	Big Prairie	Condon	Spotted Bear	
	Gallatin	Bozeman	Livingston		
	Helena	Canyon Ferry	Helena	Townsend	
	Lewis & Clark	White Sulphur			
	Lolo	Bonita	Seeley Lake		
1950	Flathead	Condon	Spotted Bear	Swan Lake	
	Gallatin	Livingston			
	Lewis & Clark	Musselshell	Sun River	Teton	White Sulphur
	Lolo	Bonita	Seeley Lake		
1951	Beaverhead	Wisdom			
	Bitterroot	Sula	West Fork		
	Gallatin	Bozeman	Gardiner	Livingston	
	Helena	Canyon Ferry	Lincoln	Townsend	
	Lewis & Clark	Musselshell	White Sulphur		
	Lolo	Bonita	Seeley Lake		
1952[1]					
1953	Beaverhead	Madison			
	Bitterroot	Sula	West Fork		
	Deerlodge	Boulder	Deerlodge	Philipsburg	Whitehall
	Gallatin	Bozeman	Gardiner	Livingston	
	Helena	Canyon Ferry	Lincoln	Townsend	
	Lewis & Clark	Musselshell	White Sulphur		

[1]District Rangers' reports not made because of regionwide budworm surveys by entomologists of the Bureau of Entomology and Plant Quarantine, Coeur d'Alene, Idaho.

Table 12.--*Estimated gross acreages of host forests visibly defoliated annually by the western spruce budworm in the Northern and Intermountain Regions, 1948 through 1971*

Year	Northern Region: Northeast Washington	Northern Region: Northern Idaho	Northern Region: Montana	Northern Region: Total	Intermountain Region: Southern Idaho	Intermountain Region: Western Wyoming	Intermountain Region: Utah	Intermountain Region: Total	Grand total
1948			270,060	270,060					270,060
1949		25,280	406,000	431,280					431,280
1950		30,160	689,000	719,160					719,160
1951		53,400	1,142,600	1,196,000					1,196,000
1952		268,440	1,644,610	1,913,050	1,000,000			1,000,000	2,913,050
1953		261,400	1,839,300	2,100,700	500,000			500,000	2,600,700
1954		297,080	1,942,660	2,239,740	1,000,000			1,000,000	3,239,740
1955		262,180	3,210,470	3,497,650	1,175,000			1,175,000	4,647,650
1956		263,070	4,153,780	4,416,850	1,127,540			1,127,540	5,544,390
1957		(2)	(2)	4,663,850	1,172,940			1,172,940	5,836,790
1958		(2)	(2)	4,894,690	974,710			974,710	5,869,400
1959		(2)	(2)	4,894,690	499,000			499,000	5,393,690
1960		89,480	2,540,640	2,630,120	516,500			516,500	3,146,620
1961		3,220	2,817,810	2,821,030	1,425,000			1,425,000	4,246,030
1962		1,030	2,894,930	2,895,960	1,641,000			1,641,000	4,536,060
1963[1]	10,200	114,670	1,897,010	2,021,880	1,632,100			1,623,100	3,644,980
1964[1]	2,800	268,100	1,921,490	2,192,390	2,276,000		20,000	2,296,000	4,488,390
1965		732,750	2,581,450	3,314,200	1,495,100	10,000	10,000	1,515,100	4,829,300
1966		824,420	795,130	1,619,550	958,400	33,800		992,200	2,611,750
1967		742,390	1,775,310	2,517,700	163,900	54,700	100	218,700	2,736,400
1968		1,703,520	2,874,920	4,578,440	395,300	109,800	400	505,500	5,083,940
1969		1,480,530	2,537,040	4,017,570	463,200	80,800	400	544,400	4,561,970
1970		1,850,500	1,807,800	3,658,300	239,200	68,400	120	307,720	3,966,020
1971		1,760,060	2,532,800	4,292,860	343,300	30,600		373,900	4,666,760

[1]Surveys of budworm outbreaks performed by the Pacific Northwest Region (Region 6) at Portland, Oregon.
[2]Regional acreage not itemized by States.

Table 13.--*Major outbreak cycles of western spruce budworm in the Northern and Intermountain regions since 1926*

Outbreak cycle	Forest Service Region	State	Duration	Peak year	Management units[1]
			Years		
I	Northern	Idaho	1926-33	1930	Bitterroot, *Clearwater*, Coeur d' Alene, *Nezperce*, St. Joe National Forests
II	Northern	Montana	1945-65	1959	Beaverhead, *Bitterroot*, *Deerlodge*, Flathead, *Gallatin*, *Helena*, *Lewis and Clark*, Lolo National Forests *Garnet Range* area of the Bureau of Land Management Yellowstone National Park (also in Wyoming)
III	Intermountain	Idaho	1954-58	1955	*Boise*, Challis, *Payette*, *Salmon*, Sawtooth, Targhee National Forests
IV	Intermountain	Idaho	1961-66	1964	*Challis*, *Payette*, *Salmon*, Sawtooth, Targhee National Forests
V	Northern	Montana	1967-	--	*Bitterroot*, Deerlodge, Flathead, *Gallatin*, *Helena*, Lewis and Clark, *Lolo* National Forests Garnet Range area of the Bureau of Land Management Flathead Indian Reservation
		Idaho	1967-	--	Bitterroot, *Clearwater*, *Nezperce* National Forests

[1]Based on annual Regional infested acreages (tables 4-8); units having 100,000 or more infested acres for at least 3 years of the cycle are italicized.

Table 14.--*Size and variation of populations of western spruce budworm by life stages and sampling units, 1950 through 1965*

Sampling unit	Year	Tree sp.[1]	Number of units: Minimum	Maximum	Average	Location	Reference
Eggs per egg mass	1959	DF			42.0	Montana	*U224*
	1960	DF			40.8		
Egg masses per 1,000 in² of foliage	1959	WF	5.6	31.8	14.5	S. Oregon/N. Calif.	*15*
	1960	WF	1.3	12.7	6.9		
	1961	WF	.2	26.9	6.6		
	1962	WF	.2	16.7	6.2		
	1963	WF	0	2.3	.8		
	1964	DF			15.0	Colorado	*72*
	1965	DF			15.0		
	1962	DF	2.0	28.0	14.5	S. Idaho	*U294*
		DF	3.0	32.0	3.7		*U294*
	1963	DF	1.1	25.2	9.6		*U292*
		DF	.6	10.2	5.5		*U292*
	1964	DF	4.2	36.7	14.4		*U293*
		DF	3.5	10.6	7.6		
	1958	DF	0	20.5	8.2	Montana	*U238*
	1959	DF	0	36.6	10.4		*U223*
	1960	DF	0	11.0	3.6		
Instar II budworm per 100 in² bole bark	1950	DF	3.0	29.0	11.2	Montana	*U42*
	1951	DF	3.01	185.0	82.5		*U46*
Instar II budworm per ft² bole bark	1956	DF	.8	222.8	34.6	Montana	*U218*
		DF	.1	10.8	3.8		
		DF	.9	118.3	43.3		
		DF	2.1	233.9	38.3		
		DF	2.3	129.5	55.8		
		DF	0	49.2	19.2		
		DF			62.9		
		DF	4.2	23.9	12.4		
		DF	3.9	14.1	9.6		
		DF	.4	8.3	4.8		
		DF	.4	50.2	18.6		
	1959	DF	0	101.4	19.1		*U238*
Instar V budworm per 1,000 in² foliage	1965	DF	36.5	46.5	40.7	Montana	*118*
		ES	19.4	50.9	30.0		
		SF	35.5	59.4	45.3		
Pupae per 15-inch foliage twig	1965	DF	0	.8	.2	S. Idaho	*U143*
		DF	.2	1.9	0.7		
		DF	0	3.0	2.0		
		DF	.2	1.9	.5		
Emerged moths per 15-inch foliage twig	1959	DF	0	3.5	1.1	Montana	*U238*
	1960	DF			1.0		*U223*

[1]Symbols: DF, Douglas-fir; WF, white fir; ES, Engelmann spruce; SF, subalpine fir.

Table 15.--*Statistical significance of correlations between some measured and subsequent metamorphic populations of the western spruce budworm and intervening defoliation levels in 25 Douglas-fir stands in Montana (from Terrell and Fellin (U238))*

Population	1958-1959 hibernating larvae	1959 defoliation	1959 emerged moths	1959 egg masses
1958 egg masses per 1,000 in² foliage	Not significant r = +0.395 at p=0.05, r=0.423	Highly significant r = +0.673 at p=0.01, r=0.505	Not significant r = 0+.367 at p=0.05, r=0.413	Significant r = +0.434 at p=0.05, r=0.396
1958-1959 hibernating larvae per ft² bole bark		Highly significant r = +0.542 at p=0.01, r=0.537	Not significant r = +0.228 at p=0.05, r=0.423	Not significant r = +0.158 at p=0.05, r=0.423
1959 defoliation percentage			Highly significant r = +0.650 at p=0.01, r=0.526	Highly significant r = +0.667 at p=0.01, r=0.505
1959 emerged moths per 15-in foliage twig				Highly significant r = +0.862 at p=0.01, r=0.526

Table 16.--*Measurements of four successive metamorphic stages of the western spruce budworm and of the intervening percentage of defoliation in 25 Douglas-fir stands in Montana, 1958-1959 (from Terrell and Fellin (U238))*

	Plot	1 Egg masses per 1,000 in^2 1958	2 Overwintering larvae per ft^2 1959	3 Percentage of defoliation 1959	4 Moths per 15 in. twig 1959	5 Egg masses per 1,000 in^2 1959
1	Bitterroot	0.58	1.5	8.6	0.00	0.00
2	Rock Creek	9.80	--	44.3	--	10.80
3	Blackfoot	11.44	14.5	42.3	3.20	16.56
4	West Continental	13.40	36.9	43.7	0.40	11.66
5	South Continental	16.12	13.0	62.2	1.40	7.78
6	Pioneer	0.94	1.6	35.2	0.10	0.32
7	Lima	0.50	0.1	13.5	0.05	0.24
8	Ruby	0.98	10.2	11.3	0.25	3.26
9	Madison	17.66	5.9	34.7	0.60	18.46
10	Hebgen	0.00	0.5	0.3	0.00	0.18
11	Centennial	4.74	28.1	54.5	0.90	12.64
12	Tobacco Root	1.34	0.0	1.8	0.00	0.00
13	Lincoln	12.66	101.4	72.7	2.65	21.98
14	Marysville	4.86	12.3	53.3	2.70	35.18
15	Elkhorn	6.30	8.6	50.1	1.15	10.62
16	Big Belt Mts.	2.04	0.1	4.0	0.50	1.10
17	Deep Creek	20.48	2.2	36.8	1.85	15.66
18	Smith River	14.64	--	84.4	2.70	21.32
19	White Sulphur	6.88	3.7	90.0	3.50	36.58
20	Bridger	12.92	3.0	67.5	0.65	10.36
21	Crazy Mts.	10.32	35.3	12.9	0.65	3.92
22	Hyalite	3.84	---	30.2	---	3.56
23	Pine Creek	19.16	84.5	92.8	0.55	7.28
24	Mill Creek	7.40	1.8	11.8	0.15	2.32
25	Slough Cr. (YNP)	5.14	55.5	55.0	1.15	4.08
	Total	204.14	420.7	1,013.9	25.10	255.86
	Average	8.16	19.1	40.6	1.09	10.24

Table 17.--*Residual effects on major forest resources of forestwide host tree damage caused by outbreaks of the western spruce budworm*

Forest use	Tree age class	Nature of tree damage	Residual effect of damage	Impact[1]	Importance[1]
Commercial	Old-growth	Light to heavy defoliation	Reduced radial and longitudinal growth.	-	S/RC
			Increased host tree susceptibility to subsequent lethal bark beetle attack, with consequent diminished timber yield.	-	G/RC
		Top killing	Diminished timber yield.	-	G/NR
			Increase in subsequent fungal wood rot, with consequent diminished wood quality and timber yield.	-	M-G/NR
			Increased host tree susceptibility to subsequent attacks of bark and engraver beetles or wood-boring insects, with consequent diminished timber yield.	-	G/NR
		Mortality	Reduced timber yield.	-	S-G/NR
			Created openings in the forest canopy for possible establishment of seedlings of		
			desirable tree species.	+	S-M/RC
			undesirable tree species.	-	S-M/NR
			herbs and shrubs that inhibit tree regeneration.	-	S-M/RC
			herbs and shrubs that aid tree regeneration.	+	S-M/RC
		Budworm-infested cones	Loss of seed source in good cone-production years.	-	S-G/RC
		Physiologic cone abortion	Loss of seed source for one or more years.	-	S-G/RC
	Immature	Light to heavy defoliation	Reduced salability of Christmas trees.	-	G/RC
			Reduced radial and longitudinal growth, with consequent diminished timber yield of crop trees at end of fixed rotation.	-	S/RC
			Induced adventitious budding, with consequent foliage and crown form qualities undesirable for Christmas trees.	-	S-G/NR
			Natural thinning resulting from possible accelerated decline of intermediate or suppressed trees.	+	S-G/NR
	Immature	Death of terminal leader from defoliation or stem mining	Height growth delayed.	-	S-M/RC
			Induced multiple terminals, with consequent		
			deformed Christmas tree crowns	-	G/RC
			stem crook, a timber defect.	-	S-G/NR
		Top killing, irrecoverable	Height growth terminated.	-	G/NR
			If in crop trees, reduced growing stock.	-	S-M/RC
			Increased susceptibility of remaining stem to fungal wood rot, with consequent diminished wood quality or yield.	-	S-G/NR
			Increased susceptibility of host tree to subsequent lethal attacks of bark or engraver beetles, with consequent diminished timber yield.	-	S-G/NC
		Top killing, recoverable	Height growth delayed.	-	S-M/RC
			New terminals produced, with consequent stem crook, a timber defect.	-	S-G/NR
		Mortality	Established optimum-density growing stock destroyed, with consequent		
			lowered yield.	-	S-G/NR
			expenditure in time and funds to replace.	-	S-G/RC
			Created openings in the forest canopy for possible establishment of seedlings of		
			desirable tree species.	+	S-M/RC
			undesirable tree species.	-	S-M/RC
			herbs and shrubs that inhibit tree regeneration.	-	S-M/RC
			herbs and shrubs that aid tree regeneration.	+	S-M/RC
			Possible natural thinning of overstocked stands by tree groups or individual trees.	+	S-G/RC
			Increased fire hazard from accumulated dead trees or living trees with budworm-killed twigs, branches, or tops.	-	S-G/RC

(con. next page; for footnotes see end of table)

ble 17. (con.)

Forest use	Tree age class	Nature of tree damage	Residual effect of damage	Impact	Importance
tershed	All	Light to heavy defoliation	Interception of rainfall and subsequent loss by evaporation may be reduced, with consequent increase in water yield.	+	S-M/RC
			Increased spring runoff from snowmelt, with possibilities of accompanying increased erosion, sedimentation, or streambed scouring.	-	S-M/NR
			Reduced transpiration, with consequent increase in water yield.	+	S-M/RC
		Mortality, without replaced ground vegetation	Reduced interception of rainfall and snow, with possible consequent		
			immediate increase in water yield from rainfall.	+	S-M/RC
			increased water yield from spring snowmelt.	+	S-M/RC
			increased erosion, sedimentation, streambank damage, flooding.	-	S-G/NR
rage	All	Mortality	On suitable sites, forbs, grasses, or shrubs may become established, with consequent increased forage		
			available to grazing livestock and game animals.	+	S-M/RC
			not available to these animals because of standing or fallen dead trees	-	S-M/NR
			Reduced animal access to established forage in sparsely stocked forests because of litter from standing or fallen dead trees.	-	S-G/RC
ldlife abitat	Pole-size or old-growth	Heavy defoliation	Reduced concealment for crown-inhabiting birds and small mammals.	-	S-G/RC
			Reduced cone production, with consequent loss of food seed for squirrels and some birds.	-	S-G/RC
	Old-growth	Mortality	Increased roosting sites for raptors, increased habitats for woodpeckers, flickers, and sparrow hawks afforded by standing dead trees.	+	S-M/RC
			Inhibited movement of larger animals from litter of standing or fallen dead trees.	-	S-G/RC
	All	Mortality	Created openings in hitherto closed-canopy forests and possible establishment of forbs, grasses, and shrubs, with consequent		
			population increases of rodents, small mammals, and their prey birds or animals.	+	S-G/RC
			seasonal population increases in domestic livestock	-	S-M/RC
			seasonal population increases in larger browsing or fruit-eating mammals.	+	S-G/RC
			removal of protective cover for larger mammals.	-	S-G/RC
creation	All	Heavy defoliation	Lessened privacy and protection from elements for picnickers and campers.	-	S-M/RC
			Reduced esthetic values of areas dependent on trees for landscaping.	-	S-M/RC
	Immature	Mortality	In picnic sites, campgrounds, summer or winter homes and resorts		
			reduced landscape esthetics.	-	S-G/RC
			increased fire hazard from accumulated dead trees or living trees with dead twigs, branches or tops.	-	S-G/RC
			increased danger to life and property from falling dead trees.	-	S-G/NR
			increased availability of fuelwood.	+	S-G/NR
	Old-growth	Top killing	Created hazard to recreationists from falling, rotted tree tops.	-	S-G/NR
		Mortality	Created hazard to recreationists from falling dead trees.	-	S-G/NR
			Increased maintenance of roads and trails from fallen dead trees.	-	S-G/NR
			Increased opportunities for ornithologists and recreationists to view birds using dead trees for roosting and nesting.	+	S-M/NR
			Increased opportunities for photographers using photogenic dead trees for landscape composition.	+	S-G/NR
			Expenditures for regeneration or large-tree replacement to maintain tree-oriented landscapes.	-	S-G/RC
	All	Currently infested trees	Nuisance of suspended larvae or dropping frass from overhead host trees in picnic sites and campgrounds.	-	S-G/RC

[1]Symbols: "Impact" column: - means detrimental effect; + means beneficial effect.
"Importance" column: S, slight; M, moderate; G, great; RC, temporary or recoverable; NR, permanent or nonrecoverable.

Table 18.--*Primary parasites of the western spruce budworm recovered in Douglas-fir forests in Montana between 1956 and 1959 (from Dodge (U56))*

Group	Species	Stage of host affected: Attack	Stage of host affected: Emergence	Control effect[1]
I	*Trichogramma minutum* Riley (Hymenoptera: Chalcididae)	Egg	Egg	Poor
II	*Glypta fumiferanae* (Viercek) (Hymenoptera: Ichneumonidae)	II Larvae	IV or V Larvae	Very good
	Apanteles fumiferanae Viercek (Hymenoptera: Braconidae)	II Larvae	IV or V Larvae	Very good
III	Several genera of flies (Diptera: Sarcophagidae)	V or VI Larvae	Pupae	Fair
	Agria affinis (Fallen) (Diptera: Sarcophagidae)	V or VI Larvae	Pupae	Fair
	Phytodietus fumiferanae Rohwer (Hymenoptera: Ichneumonidae)	V or VI Larvae	Pupae	Poor
IV	*Phaeogenes hariolus* (Cresson) (Hymenoptera: Ichneumonidae)	VI Larvae or Pupae	Pupae	Fair
	Ictoplectis quadricingulatus Provancher (Hymenoptera: Ichneumonidae)	VI Larvae or Pupae	Pupae	Poor

[1]Estimated; based upon abundance of the parasites and the percentage of parasitism accomplished.

ble 19.--*Forest lands aerially sprayed with chemical insecticides to control western spruce budworm populations in Idaho, Montana, and Wyoming, 1952 through 1971*[1]

ar	National Forest or Park[2]	Type of treatment	Insecticide used: Toxicant	Insecticide used: Toxicant/acre	Acreage treated
			IDAHO		
53	Nezperce N.F.	Operational	DDT	1.0 lb.	16,070
55	Nezperce N.F.	Operational	DDT	1.0 lb.	70,710
	Boise N.F.	Operational	DDT	1.0 lb.	621,210
	Payette N.F.	Operational	DDT	1.0 lb.	216,000
					907,920
56	Boise N.F.	Operational	DDT	1.0 lb.	211,090
	Challis N.F.	Operational	DDT	1.0 lb.	10,880
	Clearwater N.F.	Operational	DDT	1.0 lb.	119,370
	Payette N.F.	Operational	DDT	1.0 lb.	98,110
	Salmon N.F.	Operational	DDT	1.0 lb.	139,800
	Targhee N.F.	Operational	DDT	1.0 lb.	16,010
					595,260
57	Boise N.F.	Operational	DDT	1.0 lb.	92,370
	Challis N.F.	Operational	DDT	1.0 lb.	20,110
	Payette N.F.	Operational	DDT	1.0 lb.	374,180
	Salmon N.F.	Operational	DDT	1.0 lb.	55,610
	Targhee N.F.	Operational	DDT	1.0 lb.	118,360
					660,630
63	Salmon N.F.	Experimental	DDT	0.5 lb.	16,500
	Targhee N.F.	Experimental	Carbaryl	1.6 lb.	2,500
		Experimental	Carbaryl	0.8 lb.	2,500
		Operational	DDT	0.0 lb.)	
		Operational	DDT	0.5 lb.)	190,000
		Operational	DDT	1.0 lb.)	
					211,500
64	Salmon N.F.	Operational	DDT	0.5 lb.	39,200
		Operational	DDT	1.0 lb.	485,870
		Experimental	Dimethoate	4.0 oz.	1,080
		Experimental	Mexacarbate	1.6 oz.	60
		Experimental	Pyrethrins	0.01 lb.	60
		Experimental	Dichlorovos	0.1 lb.	20
					526,290
65	Salmon N.F.	Experimental	Malathion	13.0 fl. oz.	4,200
				9.0 fl. oz.	3,950
					8,150
66	Salmon N.F.	Experimental	Mexacarbate	2.4 oz.	4,860
67	Sawtooth N.F.	Experimental	Mexacarbate	2.4 oz.	2,300
69	Nezperce N.F.	Experimental	Mexacarbate	2.4 oz.	6,000
71	Nezperce N.F.	Experimental	Mexacarbate	2.4 oz.	9,000

(con. next page; for footnotes see end of table)

Table 19. (con.)

Year	National Forest or Park	Type of treatment	Insecticide used: Toxicant	Insecticide used: Toxicant/acre	Acreage treated
			MONTANA		
1952	Bitterroot N.F.	Experimental	DDT	1.0 lb.	12,000
1953	Helena N.F.	Operational	DDT	1.0 lb.	117,140
1955	Bitterroot N.F.	Operational	DDT	1.0 lb.	169,090
	Gallatin N.F.	Operational	DDT	1.0 lb.	77,440
					246,530
1956	Beaverhead N.F.	Operational	DDT	1.0 lb.	251,540
	Helena N.F.	Operational	DDT	1.0 lb.	153,630
	Deerlodge N.F.	Operational	DDT	1.0 lb.	106,800
	Lewis & Clark N.F.	Operational	DDT	1.0 lb.	253,910
					765,880
1957	Beaverhead N.F.	Operational	DDT	1.0 lb.	240,770
	Deerlodge N.F.	Operational	DDT	1.0 lb.	245,330
	Gallatin N.F.	Operational	DDT	1.0 lb.	113,790
	Lewis & Clark N.F.	Operational	DDT	1.0 lb.	113,110
	Yellowstone N.P.	Operational	DDT	1.0 lb.	2,380
					715,380
1958	Helena N.F.	Experimental[3]	DDT	1.0 lb.	6,000
			DDT + Genite	1.0 lb. + 1.0 lb.	6,100
			DDT + Genite	1.0 lb. + 0.5 lb.	6,100
					18,200
1959	Bitterroot N.F.	Operational	DDT	1.0 lb.	126,880
1960	Gallatin N.F.	Operational	DDT	1.0 lb.	66,240
				0.5 lb.	51,610
					117,850
1962	Deerlodge N.F.	Operational	DDT	0.5 lb.	96,590
	Helena N.F.	Operational	DDT	0.5 lb.	209,810
	Lewis & Clark N.F.	Operational	DDT	0.5 lb.	145,360
					451,760
1963	Bitterroot N.F.	Operational	DDT	0.5 lb.	110,190
		Experimental	Malathion	1.0 lb.	40
		Experimental	Malathion	0.5 lb.	13,510
	BLM (Beaverhead	Operational	DDT	0.0 lb.)	
	N.F.)	Operational	DDT	0.5 lb.)	18,000
		Operational	DDT	1.0 lb.)	
	Deerlodge N.F.	Operational	DDT	0.5 lb.	82,320
	Helena N.F.	Operational	DDT	0.5 lb.	35,130
	Lewis & Clark N.F.	Operational	DDT	0.5 lb.	105,080
	Lolo N.F.	Operational	DDT	0.5 lb.	64,400
		Experimental	Phosphamidon	1.0 lb.	5,000
					433,670

(con. next page; for footnotes see end of table)

Table 19. (con.)

Year	National Forest or Park	Type of treatment	Insecticide used: Toxicant	Insecticide used: Toxicant/acre	Acreage treated
			MONTANA (con.)		
1964	Helena N.F.	Experimental	Malathion	12.0 fl. oz.	26,290
	Deerlodge and Lolo N.F.'s	Experimental	Malathion	12.0 fl. oz.	131,410
	Lolo N.F.	Experimental	Malathion	9.0 fl. oz.	160
					157,860
1965	Bitterroot N.F.	Experimental	Mexacarbate	2.4 oz.	1,080
		Experimental	Naled	6.4 oz.	1,160
	Gallatin N.F.	Experimental	Malathion	13.0 fl. oz.	640
	Lewis & Clark N.F.	Experimental	Malathion	9.0 fl. oz.	1,300
		Experimental	Malathion	13.0 fl. oz.	1,610
					5,790
1966	Bitterroot N.F.	Experimental	Mexacarbate	2.4 oz.	5,360
	Beaverhead N.F.	Operational	Malathion	13.0 fl. oz.	62,440
	Gallatin N.F.	Operational	Malathion	13.0 fl. oz.	20,590
					88,390
1968	BLM, ACM (Lolo N.F.)	Experimental	Mexacarbate	1.0 oz.	6,080
1972	Lolo N.F.	Experimental	Mexacarbate	2.4 oz.	500
			WYOMING		
1953	Yellowstone N.P.	Operational	DDT	1.0 lb.	2,000
1955	Yellowstone N.P.	Operational	DDT	1.0 lb.	55,410
1957	Yellowstone N.P.	Operational	DDT	1.0 lb.	69,300

[1]The authors gratefully acknowledge the assistance of Mrs. Shirley J. Schroeder, Administrative Assistant, Division of State and Private Forestry, Northern Region, Missoula, Montana, in compiling portions of this tabulation.

[2]Including intermingled or adjacent forest lands of other public agencies or private owners, particularly those of the U.S. Department of Interior, Bureau of Land Management (BLM), and of the Anaconda (Copper Mining) Company (ACM).

[3]The aerially applied chemicals included an insecticide (DDT) to kill current budworm populations, and an acaricide (Genite) to kill subsequent epidemic populations of the spruce spider mite that might develop.

Table 20.--*Some characteristics of selected chemical insecticides used in the Northern and Intermountain Regions from 1952 through 1971 to control the western spruce budworm*

Insecticide	Chemical classification	Degree of toxicity: LD_{50}[1] Dermal	Degree of toxicity: LD_{50}[1] Oral	Degree of toxicity: General rating[2]	Description
DDT	Chlorinated hydrocarbon	2,510	113	4	Residual insecticide (applications on needles of host tree are absorbed by budworm larvae through the cuticle, especially of the tarsi). Persistent, because of insolubility in water, low volatility, chemical stability at normal temperatures and in sunlight. Low phytotoxicity at recommended dosages. Toxic to wide variety of insects, some predaceous mites. Nontoxic to some phytophagous mites. Inexpensive and in good supply during period of use. Easily applied formulations. Accumulates in fatty animal tissues and may be passed in food chains to become physiologically detrimental or lethal to some animals.
Carbaryl (Sevin)[3]	Carbamate	4,000	850	4	Acts either as a stomach insecticide (application to host tree needles and entry through the mid-gut of budworm larvae) or as a contact insecticide (application to the surface of budworm larvae and entry through the cuticle). Cholinesterase inhibitor. Fast speed of kill. Low volatility. Intermediately residual; less than chlorinated hydrocarbons, more than organic phosphates.
Mexacarbate (Zectran)[3]	Carbamate	1,500-2,500	37	2	Stomach, contact, and residual insecticide. Highly toxic to all budworm larval instars. Nonpersistent; toxicity of application ceases in about 7-10 days; chemically unstable in sunlight. High toxicity allows low dosage rates per acre, aerial spray droplets 120 microns m.m.d. or smaller. Preliminary tests indicate low toxicity to warm-blooded animals and nontarget insects.
Dimethoate (Cygon)	Organic phosphate	400	215	3	Highly toxic to insects, mites, and some animals. Acts either as a stomach, contact, or systemic insecticide or as a fumigant (application on host tree needles vaporizes and enters budworm larvae through tracheae). Cholinesterase inhibitor. Toxicity of application nonpersistent; diminishes quickly because of chemical instability.
Dichlorovos (DDVP)	Organic phosphate	107	90	2	Highly toxic to insects and mites, and to other forms of animal life. Cholinesterase inhibitor. Contact and stomach poison, with some fumigant action.
Malathion	Organic phosphate	4,444	1375	4	Stomach insecticide, some fumigating action. Cholinesterase inhibitor. Nonpersistent; since toxic action deterioriates rapidly (48 hours), requires high initial kill of budworm larvae. Highly toxic to aquatic insects, not to fish; low toxicity to birds and mammals. Relatively costly. Protective clothing and pre- and post-spray cholinesterase tests recommended for persons handling insecticide.
Phosphamidon	Organic phosphate	143	24	2	Acts either as a contact insecticide or a systemic insecticide (insecticidal activity translocated within plant tissues to other parts of host plants). Highly toxic to insects, mites, and humans. Single field test caused significant mortality of aquatic insects and grouse, inadequate mortality of budworms, no distress to mammals. Cholinesterase inhibitor; protective clothing needed for persons handling insecticide. Mixed formulations hydrolyze quickly.
Naled (Dibrom)[3]	Organic phosphate	800	250	3	Contact insecticide and acaricide. Nonpersistent; very short residual life. Mixed formulations hydrolyze quickly. Less toxic to sixth-instar budworm larvae than mexacarbate. No harmful effects on birds and mammals when applied as an aerosol.
Pyrethrum	Organic	1,880	1,500	4	Contact insecticide. Toxic to all invertebrates except Protozoa. Toxic to fish only in direct contact. Slightly toxic to reptiles and amphibia; negligibly toxic to birds and mammals at usual field dosages. May induce hay fever symptoms in some humans. Nonphytotoxic. Use limited by specificity of target insects, short supply, high cost, and deterioriation in storage (oxidation reduces insecticidal activity up to 20% in 1 year). Insoluble in water; soluble in organic solvents and oils.

References: Washington State University (*115*), Brown (*12*), Pattee (*U194*), Scott and others (*U204*), Terrell (*U227*), Robert L. Lyon, Entomologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, California; personal communication.

[1] LD_{50}, median lethal dosage causing 50 percent mortality of test animals; expressed as amount of chemical, in milligrams, per weight of test animal, in kilograms.

[2] Low umerical values in the general rating column indicate high toxicity to man and animals; high numerical values indicate low toxicity.

[3] Proprietary name of insecticide. Names not so referenced are common names of insecticides adopted by the Committee on Insecticide Terminology, Entomological Society of America.

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JOHNSON, PHILIP C., and ROBERT E. DENTON
1975. Outbreaks of the western spruce budworm in the American northern Rocky Mountain area from 1922 through 1971. USDA For. Serv. Gen. Tech. Rep. INT-20, 144 p. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

The western spruce budworm has severely damaged more than 15 million acres of publicly and privately owned coniferous forests in this area. Abundant information from ranger district annual reports is related about the behavior of the budworm, characteristics of outbreaks of its populations, and kinds and severity of damage. This budworm has chiefly attacked the Douglas-fir, grand and subalpine firs, and Engelmann spruce; it has also attacked western larch, ponderosa pine, and western hemlock.

OXFORD: 416.11; 453--145.718.28*
KEYWORDS: defoliation damage, tortricidae (-forest damage), western spruce budworm, outbreaks, host tree species, host tree impacts, biological control, chemical control.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

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The Outlook for Particleboard Manufacture in the Northern Rocky Mountain Region

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ACKNOWLEDGMENTS

The author is grateful to the many individuals, agencies, and businesses who helped prepare this study. Because so many contributed, none will be acknowledged by name. Special thanks go to those particleboard manufacturers and engineering consultants who provided data on their own plant operations.

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ABSTRACT

National demands for particleboard panel products and raw materials supply are projected for the 1970's. Demand for particleboard (which includes fiberboard and structural particleboard) is expected to continue rapid growth through the decade. New plant capacity will use dry mill residues wherever possible. Several new plants are expected in the South, and three or four each in California, the Pacific Northwest, and the Northern Rocky Mountains. In the last of the decade, expanding production will turn to use of forest residues, which will shift plant expansion toward the major markets and away from the Northwest. Analysis of production costs indicates that in the Northern Rocky Mountains plants utilizing forest residues cannot profitably compete with plants that utilize mill residues until the existing mill residues are exhausted.

INTRODUCTION

Before attempting to assess the future of particleboard manufacturing in the Northern Rocky Mountain region, we should take a brief look at the history of particleboard. The forces that shaped the growth of the industry are still operating and must be considered when attempting to forecast future developments.

What Is Particleboard?

Surprisingly, particleboard is not easily defined. The Department of Commerce (1973) defines it as:

> ....an engineered product, matformed, consisting of machined fiber particles such as granules, chips, slivers, flakes, shavings, etc., of a controlled moisture content and size, bonded together with a synthetic resin or other added binder into panel form under controlled heat and pressure.

Although this definition is adequate, it does not differentiate particleboard from its close relatives, fiberboard and hardboard. Naming a particular product is quite arbitrary, but in this case it depends primarily on the degree of refinement of the particles and on the density of the finished board. Fiberboard and hardboard tend to use more highly refined and fibrous materials than does particleboard, which may use rather large chips or flakes. The density of the finished board separates fiberboard, at 12 to 31 pounds per cubic foot, from hardboard, at 32 to 70 pounds. Particleboard falls in between, at 35 to 55 pounds.

Although many products fall clearly into one of the three classifications, there is a great deal of overlap. The remainder of this analysis will concentrate on the products generally classed as particleboard, but of necessity will digress at times into products that could more properly be classed as either fiberboard or hardboard.

Development and Growth of the Particleboard Industry

Particleboard has been in use for a long time, but the volume of production was insignificant in relation to other wood products until the last decade. Production (and consumption) began to soar in the late 1950's and early 1960's in Europe, and somewhat later in the United States and Canada.

Although Europe is usually not thought of as a world leader in wood products, there is no question about its leadership in both the technology and production of particleboard. In 1969, European consumption was 8.9 million cubic meters, compared with 3.0 cubic meters for the United States and, although consumption in the United States seems to be growing somewhat faster, Europe still leads in particleboard production. Exports and imports of particleboard are negligible in the United States, but international influence on technology and capital equipment is not. Many of the manufacturing techniques and much of the equipment used in the United States are imported from Europe.

Growth of the particleboard industry in Europe was apparently a response to market demands for an economical wood panel. European supplies of wood, especially those suitable for plywood panels, are limited. Particleboard provides a source of reasonably priced panels that can be made from almost any type of wood (and from some nonwood materials such as sugarcane stalks).

The particleboard industry in the United States has developed for different reasons than it has in Europe. Whereas European growth was pulled along by unfilled demand, the growth in the United States was pushed by the supply of raw materials. Normal sawmill operations produce vast amounts of waste in the form of bark, edgings and trim, sawdust, and planer shavings. For years the usual disposal method was burning, sometimes as fuel, but more often as waste. Pressure against smoke pollution, combined with the economic pressure of increasing wood costs, made the use of these former wastes a necessity.

Papermills were the first to make significant use of the mill wastes. Edgings and trim from sawmills rapidly replaced roundwood as a major source of pulp chips. Particleboard manufacturers soon perfected techniques for utilizing dry planer shavings, which opened up enormous supplies of raw material that were available almost free. Planer shavings appear to be ideal for particleboard; they are relatively dry and are already close to the size and shape desired. After a minimum of drying and milling, done primarily to maintain uniformity rather than to make major changes in the particles, the shavings are ready for use. The cost of purchasing and preparing the shavings is so low that the greatest cost is often transportation of the shavings from the mills where they are produced to the plants where they are used for particleboard.

That material supply, not product demand, was the primary stimulus in the development of the domestic particleboard industry can be inferred from both the pattern of expansion and the history of prices.

The first wave of expansion was in Oregon, which has the greatest concentration of sawmills (and wood waste) in the Nation. Although Oregon is remote from the major markets, the availability of large quantities of cheap, high quality materials favored plant location there. The industry has continued to expand in the Far West; however, during the late sixties the major growth shifted from the West to the South. Rapid expansion of both lumber and plywood production in the southern pine region again create a concentration of mill waste. This time, however, the mill waste was located close to to the wood products market, and the particleboard plants followed close on the heels of the lumber and plywood mills.

In 1972, about 95 percent of the production of particleboard was split evenly between the southern pine States, with no real concentration, and the Far West, mostly

in Oregon. As of late 1973, expansion in particleboard capacity, as judged by announcements of new plants in the trade journals, appears to have slackened from its enormous growth of the past few years, when capacity more than doubled between 1968 and 1972.

The supply-push on particleboard production can also be inferred from the price of particleboard during this rapid expansion period. Like other wood products, the price of particleboard is quite volatile, but even so, particleboard prices have remained more constant over the last few years than have prices for similar and competing products such as plywood.

In January 1968, the price of 1/2-inch exterior plywood stood at $74 (per 1,000 feet); it then rose rapidly to a peak of $142 in February 1969, fell back to $74 in March 1970, rose again to a peak of $180 in March 1973, and since then has fallen again.

Particleboard prices had a similar peak and fall in 1969, but rose very little during the next 3 years (fig. 1 and 2). Although 1/2-inch exterior plywood and underlayment particleboard are not directly competing products, both are used primarily in housing construction, and so should have similar demand forces on their prices. The stable or slightly falling prices for particleboard during a long period of rising plywood prices indicate that the supply of particleboard was growing faster than the demand.

In the analysis that follows, we will first investigate the national markets for particleboard and the possible future changes in the market structure. Next we will examine the expected patterns of expansion in production capacity. We have already noted that the early expansion of the industry was geographically concentrated first in Oregon and then in the southern pine region. In assessing the manufacturing potential in any one area (such as the Northern Rocky Mountains), we cannot ignore the trends in the rest of the country. In the final portion of this analysis, we will examine the cost of particleboard manufacturing in the Northern Rocky Mountain area, with emphasis on those cost factors which would place this region at an advantage or disadvantage in comparison with other possible locations.

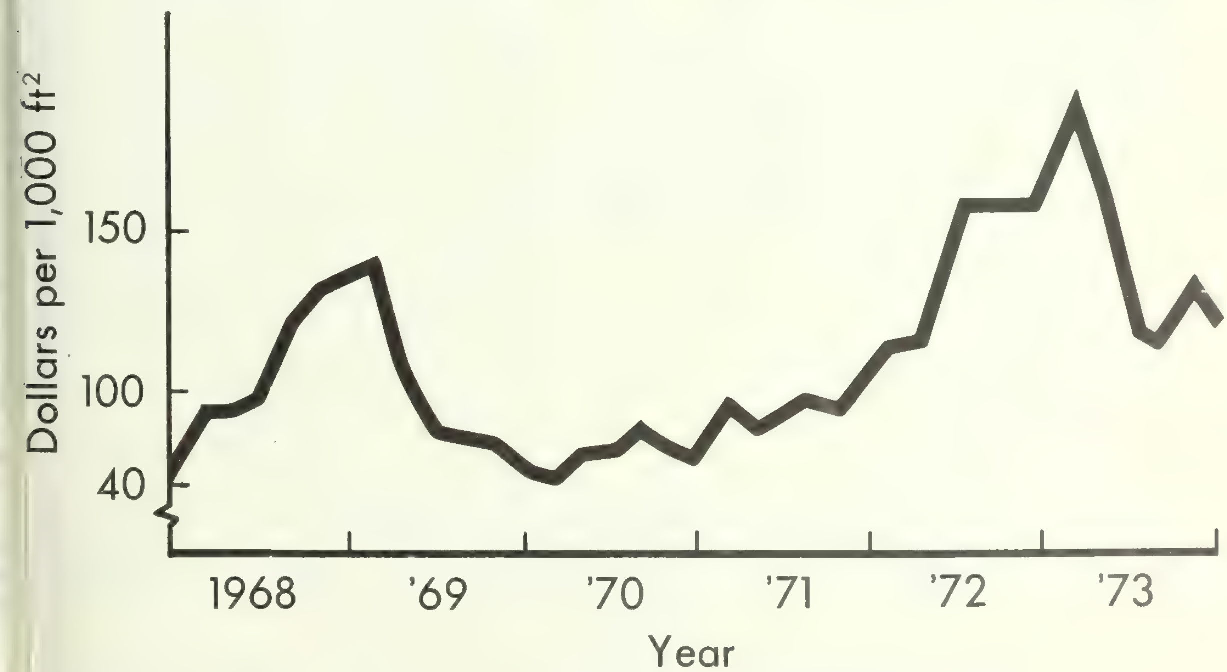


Figure 1.--Plywood prices; 1/2-inch CDX, f.o.b. west coast.
Source: Crows Plywood Newsletter 1968-1973

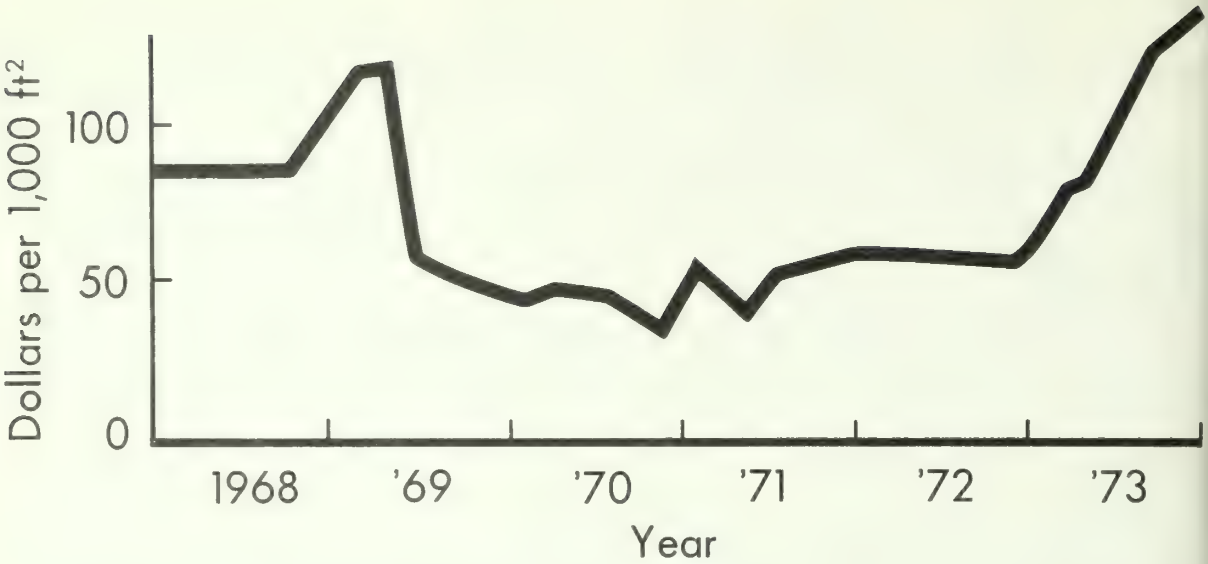


Figure 2.--Particleboard prices; 5/8-inch underlayment, f.o.b. west coast. Source: Crows Plywood Newsletter 1968-1973.

PARTICLEBOARD MARKETS

The nationwide demand for particleboard has grown rapidly in the past decade, and indications are that it will continue to grow for some time in the future. The real tions to be answered are how much increase might be expected, and what changes there t be in the product mix or geographical distribution of the demand.

The total production of matformed particleboard is shown in figure 3, along with ral possible projections through 1985. Figure 3 shows the quantity of production, the actual demand for particleboard. Although the two are closely related they are the same, and it is demand, not production, that we want to forecast. If demand for

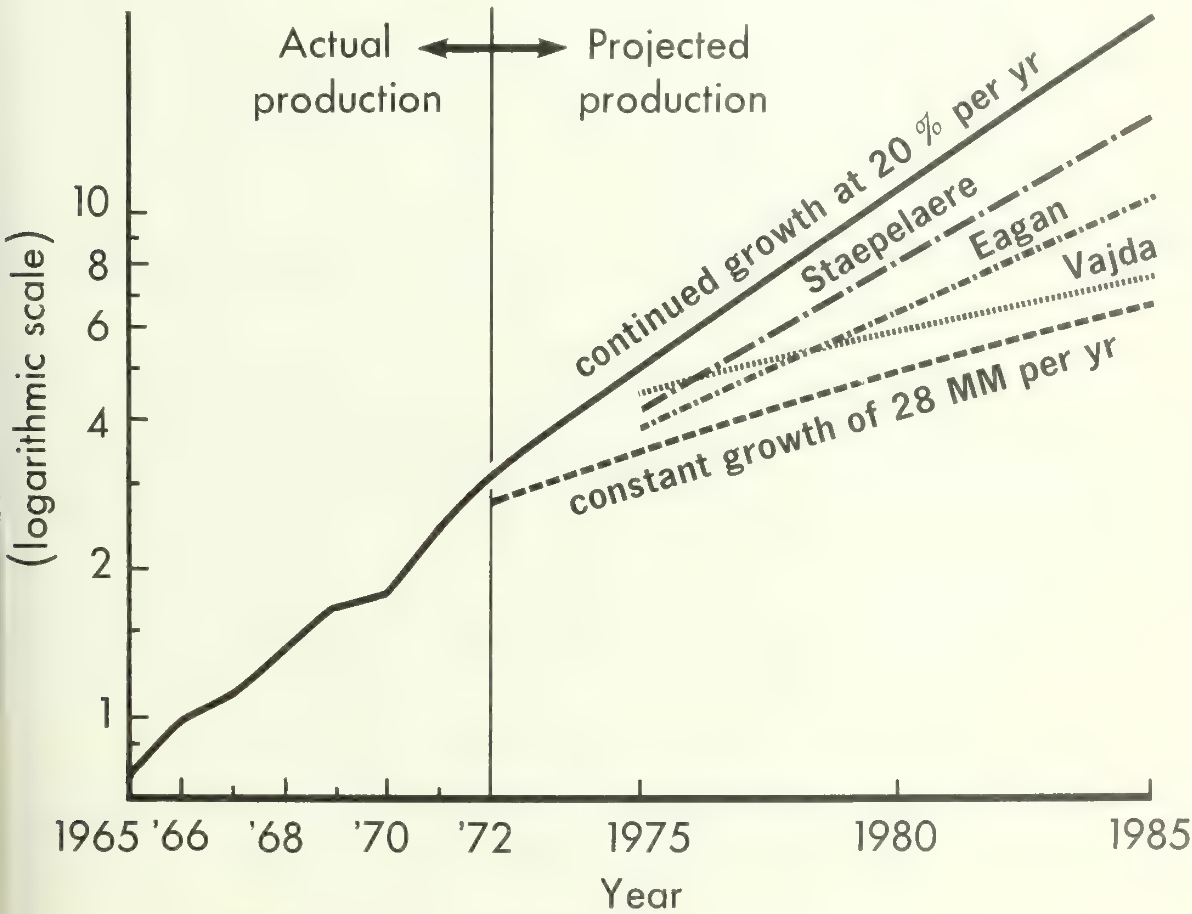


Figure 3.--Actual and projected particleboard production in the United States. Actual production source: U.S. Department of Commerce 1973.

a product is less than production during any time period, the surplus will accumulate a inventory, either at the site of manufacture or in the distribution channels. Particle board, however, is bulky and requires covered storage, so that neither the manufacturer nor the distributor is likely to attempt to accumulate much. When demand slips below production capacity, the production is restricted, so that the two are equal.

If the demand is greater than the production capacity, the effects are more subtle and difficult to measure. The excess demand can disappear by being shifted to alternat products, or it may appear as an increase in backlogged orders to the manufacturer. Data are not available to estimate either effect. If there was excess demand, however, there should be pressures for increased prices. The stable prices for particleboard ov the past 7 years indicate that demand has not significantly exceeded production, so tha we may safely use actual production as a good indicator of the demand.

Forecasts of Future Demand

Of the many techniques for forecasting product demand, the most usual is simply to extend the observed patterns of the past into the future. Two lines are shown on figure 3; each is an extension into the future based on different assumptions about the nature of the growth pattern.

The upper line (solid) is determined by finding the average percentage increase each year and extending it into the future. From a volume of about 800 million ft^2 (3/4-inch basis) in 1965, production has increased to 3.2 billion ft^2 in 1972, an avera increase of 20.8 percent per year. Extending this rate of increase gives a forecast of 5.28 billion ft^2 in 1975 and 13.6 billion ft^2 in 1980.

The lower line (dashed) projects the average amount of growth as obtained by linear regression. The average growth from 1965 to 1972 was 28 million ft^2 per year; extending this constant growth into the future yields a forecast of 3.5 billion ft^2 in 1975 and 5 billion ft^2 in 1980.

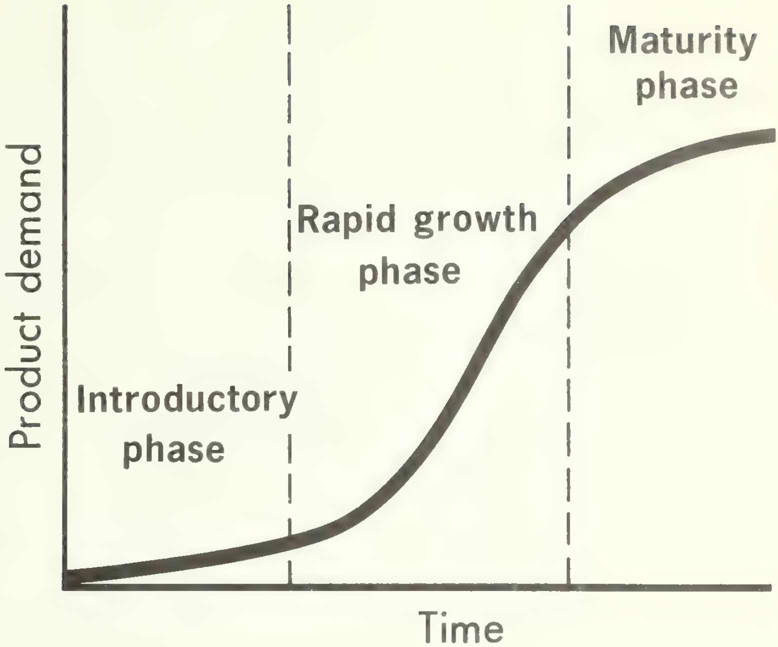
Both of these forecasting techniques are reasonable and are widely used, but in this case yield quite different forecasts. A difference between 5 and 13.6 billion ft^2 for 1980 cannot be passed over lightly. Which of the techniques is more likely to be correct depends on where particleboard is in the growth cycle.

Most products progress through a demand pattern similar to that shown in figure 4. A period of slow growth is followed by a period of rapid expansion, when the amount of growth increases each year. At some point the curvature of the growth pattern shifts, and although growth continues, it does so at an ever-decreasing rate. The period of time between introduction and maturity is highly variable, but seems to depend primaril on how specialized the product is. Very highly specialized products such as color television may go from introduction to maturity in a few years, but general-use product such as electrical energy may take many decades.

During the rapid-growth phase, a forecast based on a constant-percentage growth ca be expected to give accurate results. During the maturity phase the constant growth rate will yield a better forecast.

Particleboard has obviously passed the introduction phase and is well into the rapid growth phase, so the percentage growth forecast is the more reasonable, at least for the very short term. Rapid growth must end eventually, however, and the immediate question is how close is particleboard to its maturity. There is no way to tell excep for expert opinion, which may be subject to considerable error.

ure 4.--Typical product life cycle.



The period of rapid growth for any product can be prolonged by the development of ge new markets. When growth for the product depends on growth in the market already ved, the rate of growth decreases and maturity is achieved.

Within the past decade many new particleboard markets have opened, hence the rapid wth. The most important of the new markets have been floor underlayment in residence struction, core stock for furniture, and decking for mobile homes. A recent develop- t has been painted or decorated panels for interior walls, cabinets, and furniture. the particleboard industry must look only to these established markets, then growth l be limited, probably to the level shown by the dashed line on figure 3.

A number of potential new markets for particleboard are just now being entered or in the early speculation stage. Finished panels that are painted, embossed, or rlaid with a vinyl or wood veneer are already being produced in quantity, but are bably just starting into the rapid growth era. Of lesser magnitude is precut and e-finished shelving. First made to convert damaged panels into a salable product, lving found quick acceptance and a ready market, and is now being produced as a mary product.

Still in the early introduction stage is structural particleboard, which is intended replace plywood sheathing in subfloors, walls, and roofs. Most particleboard is pro- ed to provide uniform, smooth surfaces and good machinability. Structural boards designed for strength by using larger flake-type particles and for moisture resist- by using phenolic bonding agents rather than the usual urea resin.

Structural boards have the potential for markets much larger than any of the current of particleboard, but it is still too early to predict how large the market might r how soon it will become a major component of the total market. A structural board eing produced in Canada under the brand name "Aspenite," and a similar plant to uce a similar board is under construction in the United States. A rapid expansion tructural board production cannot come until the design of the board and the niques of manufacture are more firmly established and the product is accepted for under the various building codes which govern the use of structural materials. is well underway on both problems, but neither is near solution.

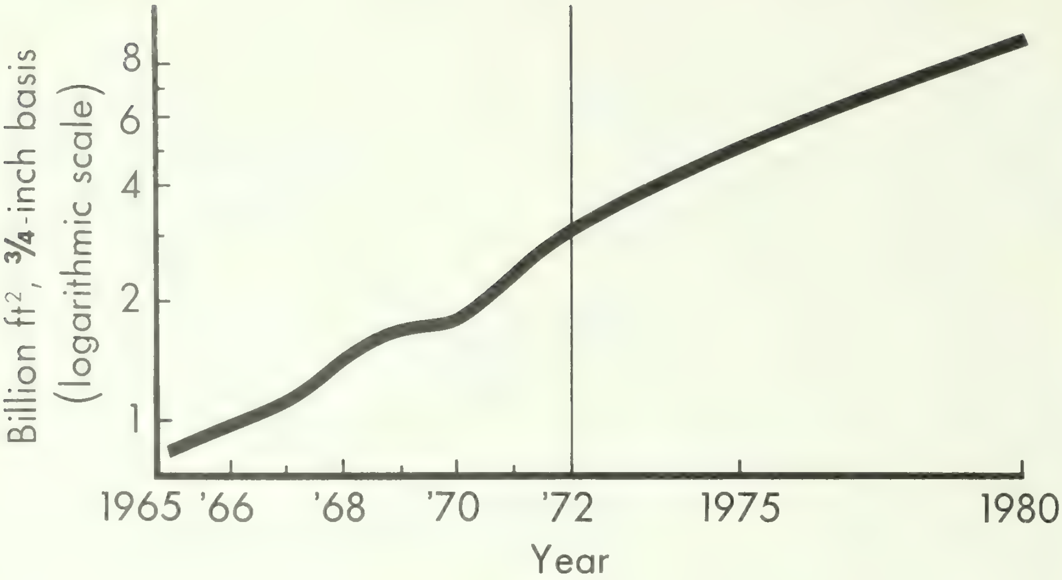


Figure 5.--Forecast of particleboard demand in the United States.

Structural board will probably not have a significant effect on the total particl board market for several years, but its introduction may be speeded up by short suppli and rising costs of plywood.

Potential products now being researched include thick panels for roof decking, corrugated panels, and particleboard-wood veneer combinations. The trade journals fairly burst with ideas for new products and new market potentials, and it appears tha particleboard is not yet close to market maturity. We can expect that the pattern of growth through the 1970's will continue at a high percentage growth rate.

Forecasting is so dependent on personal judgment that it is always comforting to find that others have arrived independently at about the same results. Figure 3 shows actual particleboard production in the United States through 1972 and projects production through 1985. Two projections were developed for this study--an upper projection based on growth continuing at 20 percent per year, and a lower projection based on constant growth of 28 million ft^2 per year. In addition, projections from three other sources are plotted: Vajda (1970) of Columbia Engineering, a consulting firm; Staepelaere (1971) for Black-Clawson, manufacturer of particleboard-producing machiner and Eagan (unpublished), Colorado State University, and the Rocky Mountain Forest and Range Experiment Station. The latter forecast was developed separately for the many end uses of particleboard, such as furniture, mobile homes, and so on, and was tied t projected increases (1947-1970 data base) in population and gross national product.

Although none of these forecasts are identical, they are in close agreement considering the uncertainties involved in projecting the demand for any rapidly growing product so far into the future. All three of the forecasts shown were made before th actual demands for 1971 and 1972 were known.

The forecast of total particleboard demand shown in figure 5 will be used throug out the remainder of this analysis. It combines published forecasts and the maximum expected growth from figure 3; and like all forecasts it is, in the end, based primar on individual judgment.

Actual demand (billion ft^2)		Forecast demand (billion ft^2)	
1965	0.8	1973	3.6
1966	1.0	1974	4.2
1967	1.115	1975	4.8
1968	1.425	1976	5.5
1969	1.700	1977	6.4
1970	1.760	1978	7.2
1971	2.460	1979	8.0
1972	3.120	1980	9.0

Figure 5.--(con.)

Regional Distribution of Markets

Data are not available on the regional distribution of particleboard markets, but me published estimates are available which provide a sufficient breakdown for the esent purposes. Vajda (1970) has estimated the following regional distribution for 70, based on analysis of mill shipments:

Region	*Percentage of total market* (*Percent*)
South	37
North Central	25
Northeast	18
West	20

Richard Bruce (1970) estimated the regional markets for particleboard by relating to the demand for plywood (for which data are available). This method gives entical results for the two Northern regions, but indicated 32 percent for the West d 25 percent for the South. Relating particleboard to plywood tends to ignore the fects of the furniture industry, which is a heavy user of particleboard but not of ywood, and which is very concentrated in the Southern States. For that reason, jda's regional breakdown will be used.

There are, of course, market concentrations within these broad geographic regions, nerally within the major metropolitan areas. Bruce estimates concentrations of 13 rcent (out of 25 percent for the whole North Central region) in the Chicago-lwaukee area, and 16 percent (out of 18 percent for the Northeast) concentrated in the ston-Washington coastal strip.

Some small changes in the regional distribution have been projected by Vajda, but view of the uncertainty about the level of the total market, they are of minor portance. Growth caused by expansion of existing markets can be expected to maintain e same geographical distribution as we now have. The opening of new markets such as r structural board may change the distribution somewhat, but we can expect that over e next 5 to 10 years the changes will be minimal.

Product Differentiation Within the Particleboard Market

Although it is easily recognized that not all particleboard is the same, there is considerable uncertainty as to how many different varieties exist.

The Commercial Standard CS 236-66 (U.S. Department of Commerce 1966) lists 10 types of board. Boards are classed by type of binder (two types), density (three grades) and strength (two classes). In reporting production statistics, however, the Department of Commerce, of which the Bureau of Standards is a part, lists only two types: floor underlayment, and other. The picture one gets from the trade journals is that there are as many types as there are manufacturers. There is, obviously, some product differentiation.

The Department of Commerce practice of reporting only two product categories appears to be sufficient for the present. The "underlayment" category actually includes all boards reported by manufacturers as going to nonindustrial buyers. It consists primarily of urea resin-bonded (interior use only), medium density (37-50 pounds) boards of class 1 strength (low strength), in normal 4- by 8-foot panel sizes. Underlayment is a general, commodity-type product. It is not easy to distinguish one producer's board from another, and most users probably don't care what it is or where it came from, so long as it meets minimum standards. Price and availability are the most important attributes for this type of product. Much of this type of board ends up in applications such as cabinets and shelves, but its major use is as a floor underlayment. In 1972, 30 percent of the total production was classed as underlayment.

The "other" category of the Department of Commerce is usually referred to as industrial board, and is quite differentiated compared to underlayment. In general, industrial board is higher quality than underlayment, where the definition of quality changes from user to user. Usually, smoother surfaces and edges and easy machinability are the desired characteristics. At times, strength, screw-holding ability, and appearance are important. In addition to physical differences, industrial board has no standard sizes, and is produced in a wide variety of thicknesses and panel sizes. There is a strong trend toward surface finishing at the plant, which may include painting, embossing, and overlayment with vinyl or wood veneer.

Much of the product differentiation in the industrial market is superficial; the basic product is much the same but is changed slightly by modifying the density or the finished size to suit the customer's needs. The end effect, however, is that the industrial board market has no real standards, in either the product or the price.

Structural particleboard will warrant a classification of its own as soon as production becomes significant. Structural board, like underlayment, will be a standardized product used primarily in housing construction. The requirement for a standardized product that will be imposed by the building codes will make product differentiation among manufacturers difficult, although several types of board may eventually be lumped together in the general category of structural board.

OUTLOOK FOR PRODUCTION

The demand for particleboard, and its production, will increase substantially over e next few years. The current production of a little over 3 billion ft^2, 3/4-inch sis, was produced by 62 plants, at an average output of 48 million ft^2 per plant. creases over the next 2 years can come only from new plants already started or from creased capacity at existing mills. An unpublished survey by Columbia Engineering ternational, Ltd., Vancouver, B.C., of new plants and expansions already underway ows a total of 15 new plants that will be producing an additional 1.3 billion ft^2 1974. This is an average output of about 85 million ft^2 per new plant, a substantial crease over the present size; a trend that can be expected to continue. If production to continue to expand to 5.5 billion ft^2 in 1976 and 7.2 billion ft^2 in 1978, we will e an additional 12 to 14 plants under construction in 1974-1975 and 16 or 17 in 1976-77 (at an average production capacity of about 100 million ft^2 per plant).

The new plants will be located wherever they will obtain the greatest economic vantages, which will depend primarily on the type of product, the location of markets, d the availability and price of raw materials. Some insights into the expected pansion can be gained by examining the patterns of past expansions and the forces at have governed the growth of the industry.

Past Growth Patterns

In its early stages, the particleboard industry relied heavily on techniques and ocesses developed in Europe for producing boards from specially prepared chips and akes. During the late 1950's and early 1960's, processes were developed in Oregon to ke particleboard from dry Douglas-fir planer shavings. The shavings board quickly came the industry standard and firmly established the west coast as the center of rticleboard production. In 1965 about two-thirds of the nation's particleboard was oduced in the West, mostly in a small area of western Oregon. The main reason for s concentration, which is about as far from the markets as is possible, was the ormous amount of shavings produced in the Oregon sawmills. These shavings were cheap d required very little processing before being formed into boards. The very low erating costs gained by using shavings more than offset the cost of the long haul to rkets.

The rapid growth of lumber and plywood production in the southern pine States ated supplies of mill wastes similar to those of the West, but located much closer the major markets. The particleboard industry was quick to take advantage of the uation, and much of the growth since 1965 has occurred in the Southern States.

Production in the West has continued to expand, but at a much slower rate than in the South. By 1972, total capacity was about the same in the South and the West; together they produced 95 percent of particleboard. Seventy-two percent of the production in the South comes from mills constructed since 1965, but only 39 percent of the West's production is coming from the newer mills.

The pattern of faster growth in the South seems to be continuing. Of the increased capacity now under construction, 410 million ft^2 is in the West (four plants or expansions), and 870 is in the South (four plants or expansions).

The pattern of plant location around supplies of raw materials in the form of dry softwood mill waste can be expected to continue, and with the major markets remaining in the East and South, the South will continue to have a freight advantage and so see the greater growth. Depletion of easily accessible mill wastes in any area, however, may change the pattern of growth, as will any technological shift away from planer shavings.

Availability of Mill Wastes and Projected Expansion

The volume of mill waste materials produced and used in the United States is not known, but a number of estimates are available. Table 1 shows the unused portion of fine softwood mill wastes in the United States in 1970 as estimated in "The Outlook for Timber in the United States," (USDA Forest Service 1973). The techniques were not given, but the estimated unused waste corresponds with detailed studies made in Oregon and Washington in 1968 (Bergvall and Gedney 1970; Manock and others 1970). "Fine residues" includes both sawdust and shavings, both of which are usable furnish for particleboard production.

Not all mill wastes will be available for particleboard manufacture. Some of the waste is generated in small scattered mills which are either remote or have no facilities for waste collection. Production figures by mill size as reported in the annual lumber survey (Lambert 1973) conducted by *Forest Industries* were used to estimate the proportion of the total waste that is produced in small mills and would probably not be collected. There is a significant difference between the West and the South in the distribution of mill size. In the West, 90 percent of the lumber was produced in mills

Table 1.--*Estimated supplies of fine softwood mill wastes available for particleboard, 1970 and 1980*

Area	(1) Unused fine[1] residues from lumber and plywood, 1970	(2) From mills with over 25 million ft^2 capacity	(3) Estimated as available for board manufacturing, 1970	(4) Estimated increase or decrease, 1970-1980	(5) Unused waste available for board manufacturing	(6)	(7) Number of plants, 1980, at 100 million ft^2 per plant
	1,000 ft^3	[illegible]	[illegible]	*Percent*	*1,[illegible] ft^3*	*million ft^2 (3/4")*	
South	117,580	64	50	+20	45,150	452	4.5
Pacific Northwest Douglas Fir	57,883	90	50	- 8	23,964	240	2.4
Pacific Northwest Ponderosa Pine	[illegible]	90	50	- 8	9,806	98	1.0
California	83,298	90	50	- 8	34,485	345	3.5
North Rocky Mountain	60,187	90	50	+ 6	28,709	288	2.9
South Rocky Mountain	30,711	90	50	+ [illegible]	14,649	146	1.5
Total						1,569	15.8

Sources:

Column 1 USDA Forest Service 1973.
Column 2 Lambert 1973
Column 4 USDA Forest Service 1973.

[1]Fine mill wastes are sawdust and planer shavings from primary processing plants.

having an annual output of 25 million bd. ft. or more (60 percent of the mills). In the South, only 64 percent of the production was from the larger mills (29 percent of the mills). The total unused residues have been multiplied by these percentages, on the assumption that wastes from the smaller mills would be unavailable.

Not all of the available wood wastes will be used for board manufacture; some will be diverted to other uses. The paper industry has been using increasing amounts of mill wastes and we can expect to see that trend continue. Until recently, pulp manufacturers have used only coarse residues such as slabs and edgings that could be processed into pulp chips, and board manufacturers used only the dry shavings. Nobody used sawdust. Recently, both pulp and board manufacturers have found that sawdust can be used in their products and both are now using it. Supplies still exceed demand, but there already are regional shortages of mill waste.

The use of mill residues for fuel can also be expected to rise. Much of the mill residue now burned as fuel contains bark and dirt and is not acceptable as furnish for manufactured products. As traditional fuels such as oil and gas become more expensive and harder to obtain we will see a strong demand for wood residues for fuel.

Alternate uses of fine residues are expected to consume about half of the currently unused residues, with half being available for board manufacturing. (This estimate of 50 percent is strictly a guess.)

Column 4 of table 1 shows the expected increase or decrease in sawmill production over the next decade. Any change in the basic industries of lumber and plywood will have a similar effect on the volumes of residues produced.

Column 5 of table 1 is the estimated fine softwood wastes that will be available for particleboard manufacturers, in thousands of cubic feet. This is converted in columns 6 and 7 into the potential particleboard production and the number of additional plants that each geographic area could support. Enough unused fine softwood wastes were available at the end of 1970 to produce about 1.5 billion ft^2 of board. Since 1970 the industry has continued to expand, mostly in the South, so that it appears that the easily accessible mill wastes in that area must be about exhausted. In fact, recently announced expansions of 870 million ft^2 in the South are over the estimated supply, which means either that the estimated supply is too low, or that the plants expect to use some other sources of raw material. Both are probably true; at any rate, it appears that the days of cheap mill waste are about over in the South, so that the rate of expansion there will slow down, at least until the rest of the country also runs out of mill waste.

Some indication of the supply situation in the South comes from the announcement that the Evans Products plant in Moncure, N.C., is being converted from softwood mill waste furnish to rough hardwood wastes.

Expected Expansion in the West

New particleboard plants based on fine mill waste will continue to be built in the West until the easily available supplies are exhausted, which will probably occur within the next 2 or 3 years. The unused supplies of fine mill waste in the West are about evenly split among California, the Pacific Northwest, and the Rocky Mountains. The expansions most logically will come in those areas closest to the markets. Southwestern markets (mostly Los Angeles) can best be served by plants in northern California, and the Midwest market, by the Rocky Mountain States. The 1973 *Forest Industries* survey of board manufacturing lists four new western plants. Two are in Montana--at

Columbia Falls and Bonner. One is in California at Oroville and one at Medford, Oregon, which is quite close to the California border. There have been several expansions but no new plants in the rest of Oregon, and none in Washington since 1971.

This pattern of expansion is likely to continue, with several new plants in northern California and one or two more in the Rocky Mountains. Expansion should be somewhat slower in Oregon but may go faster than expected because of the industry concentration already there.

Within the next 2 or 3 years, then, most of the growth in particleboard manufacturing will be in the Western States, and will be located close to the remaining supplies of fine mill wastes. The production of particleboard from other materials, which has already started, should gain momentum so that in several years most of the growth will be based on materials other than softwood mill wastes. To predict the patterns of these further expansions we must examine the other materials available, and the products to be made from them.

Alternate Board Products and Raw Materials

Medium Density Fiberboard.--Of the new products and processes that will affect the particleboard industry in the near future, medium density fiberboard (MDF) looms the largest. Although MDF is a well-defined product, no one in the industry seems to agree as to its classification. Some of the present producers class their output with particleboard, others with hardboard. Its inclusion with particleboard is justified because it is used for the same applications as industrial grades of particleboard

The essential difference between the usual shavings-type particleboard and MDF lies in the preparation of the material. Particleboard furnish is processed at ambient temperatures and pressures through refiners that reduce the material to particles of the desired size and shape. The particles are then dried, mixed with adhesives and wax, and formed into a mat, usually with finer material on the face and coarser material in the center.

MDF furnish is processed at elevated temperature and pressure, which softens the wood and results in a finer, more fibrous particle. The fibers are then dried and blended as with particleboard, but formation of the mat requires different techniques because of the light, fluffy nature of the material. Most (but not all) MDF is made as a homogenous board, that is, with no difference in the material on the face and the core.

MDF has a smooth face (comparable to good industrial particleboard), good strength and superior edge machinability, which make it an excellent panel for furniture manufacturing. Perhaps the most important effect of the pressure refining, however, is that almost any wood furnish will make a good board. Ordinary particleboard can also use many materials, but the processing costs and board quality may suffer. Hardwoods are especially difficult to work with and some species of softwoods are also less suitable. Part of the western dominance in particleboard comes from the ease with which high quality industrial board can be made from ponderosa pine and Douglas-fir, which are found only in the Western States. There has thus been a tendency for the western manufacturing plants to produce more of the industrial board and the southern plants to specialize in the less demanding underlayment grades.

Because the MDF process can produce high quality industrial board from hardwoods and southern softwood, much of the growth in MDF production can be expected to occur close to the major markets in the South and Midwest. As usual, mill waste which otherwise constitutes a disposal problem, and is therefore very low cost, will be the preferred material.

Structural Particleboard.--Regional growth of particleboard production will also e influenced by development of structural particleboard. Structural board technology s not as well developed as is that of MDF, and there is still some uncertainty as to ow the product will be made and what materials will be used. However, structural board s not a new product. A plant in Saskatchewan, now owned by McMillan Bloedell, began roduction in 1963 of a structural board called "Aspenite." Aspenite has been quite uccessful in Canada, where it is used in structural applications and is an approved ubstitute for plywood under the building codes. The Blandin Paper Company has built plant in Grand Rapids, Minn., to produce a structural board from aspen, which they ave named "Blandex." This plant should be producing sometime in 1974. The market erformance of Blandex will be very closely watched to see if it can match the accept- nce of Aspenite in Canada. It has two large marketing hurdles to clear: the eluctance of builders to switch from plywood to a new and unknown substitute, and ull acceptance by regulatory agencies and building codes. The speed of acceptance ill probably depend more on the price and supply of plywood than on the merits of the oard itself. A prolonged shortage of plywood would force a more rapid acceptance of tructural particleboard. However, if plywood production is able to keep up with or tay ahead of demand, then production of structural board will grow very slowly.

Structural boards differ from normal particleboards in that they have greater oisture resistance and strength. Moisture resistance is easily obtained by substi- uting a phenolic resin (the same as is used for exterior plywood) for the usual urea esin. The greater strength is obtained by using larger particles, more resin, alining he particles in one direction, or by using any combination of the three. Aspenite is ade from large, thin particles (called flakes) in a random arrangement and with about .5 percent resin. The strength of the product probably could be increased by using ore resin.

The flake size used in Aspenite averages about 1-1/2 inches long, one-half to 3 nches wide, and 0.025 inch thick. Research has indicated that the width of the flake s not important and could be much smaller, but that the long length and thinness of he flake are important to strength. The flakes are made from aspen logs by a flaking rocess which cuts parallel to the grain, thus producing the long, thin flakes. A hipping action, such as is used for producing pulp chips, cuts across the grain of he wood, which makes chunks or slivers rather than the thin flakes required.

Whatever the final characteristics required for flakes, a good structural board equires flakes cut from a relatively large piece of wood; therefore, fine mill wastes re not suitable furnish. Even a coarse mill waste such as pulp chips apparently will ot work well. Structural board could be made from mill slabs and edgings, but with he strong trend toward the chipping of coarse wastes, even in the smaller mills, slabs re not a reliable source for large-scale use. The primary source of material for tructural board will be roundwood, and the industry will tend to locate where there re suitable supplies of materials close to the markets.

The Lake States are ideal for the early location of structural board manufacture. here are abundant supplies of aspen; and with the first two structural board plants sing aspen, there will be a reluctance on the part of potential manufacturers to xperiment with other species unless they must. There are large markets nearby in the orth Central States and the northeast coast. The real inducement for a northern ocation, however, is the freight advantage that a local structural board would have ver the plywood that it must displace in the marketplace. Because there is no oftwood plywood manufactured in the North, the plywood used in that area must bear reight charges from the South and the West, whereas a locally produced structural oard would not.

A structural board produced in the West or South would be competing with plywood roduced in the same area, and so would have no freight advantage. In fact, because

the particleboard is somewhat heavier than comparable plywood, it would be at a disadvantage that would grow greater as the distance to markets increased.

The rate of growth in the structural board markets is extremely difficult to predict because there is almost no history to use as a guide. Two of the forecasts mentioned earlier, however, include demand for structural boards, and are in very close agreement.

The demand forecasts for 3/4-inch structural particleboard in million ft^2 are:

	1975	*1980*	*1985*
Columbia Engineering (Vajda)	150	900	--
Rocky Mountain Forest and Range Experiment Station (Eagan)	155	820	2,975

At 80 million ft^2 per plant, these forecasts translate into 2 new plants in 1975 and 10 in 1980. With one plant (Blandin) already going, we can expect only one more in the next 2 years, followed by eight in the next 5 years--not a very rapid expansion when compared with the expected growth in particleboard and MDF. It is not until the 1980's that we can expect structural boards to become a major factor in the total wood panel market.

Summary

Expansion of particleboard production within the next few years will tend to follow the established pattern of locating close to available supplies of fine mill wastes, with closeness to markets being a secondary factor. This pattern will continue until the supplies of readily available mill wastes are exhausted.

Mill waste supplies in the South appear to be running out, so that the rapid expansion in that area will slow, with only two to four major new plants expected within the next few years. Expansion will be most rapid in northern California and the Rocky Mountain States, with three or four new plants expected in each area (at an average capacity of 100 million ft^2 per year). Oregon and Washington can expect two or three new mill waste-dependent plants.

By 1976 or 1977 we can expect that most readily available softwood mill waste will be committed to use, so that additional expansion will be based on other sources of raw material. Medium density fiberboard can be made from roundwood or rough mill wastes, either hardwood or softwood, which are widely available. We can thus expect that the next major wave of expansion (after the fine mill wastes are used up) will tend to be close to major markets--the South and Northeast.

The structural board market is expected to grow slowly during the next 5 years, with most of the growth being in the Lake States region. If aspen supplies prove to be insufficient or if there is strong price competition from the pulp industry, the structural board expansion may be forced toward the South or the Rocky Mountains. In any event, there will probably not be much growth in structural board in the West, except possibly for a couple of plants supplying local demands.

ECONOMICS OF PARTICLEBOARD PRODUCTION IN THE NORTHERN ROCKY MOUNTAIN REGION

In assessing the economics of building and operating a particleboard plant in any egion, care must be taken that our view not become so general that important details re obscured. Nevertheless, some generalizations must be made if we are to cover a easonable range of alternatives.

The first section of this analysis will deal with the costs and returns to be xpected from a plant operating on mill waste furnish. The second will deal with the stimated costs of producing a structural board from roundwood, with special emphasis n those cost factors that would vary greatly between possible locations.

Cost estimates for both capital and operating expenses have been obtained from hree sources: published materials, detailed feasibility studies for prospective plants, nd actual costs provided by operating plants. The published costs are from several ources (Gray and others 1970; Raddin 1970; Vajda 1970) and are indicated in figure 6. etailed estimated costs were provided by Columbia Engineering of Vancouver, B.C. uring the summer of 1973, seven operating particleboard plants were visited, and ctual cost data were provided by four of them. Because of the confidential nature f the data provided, the plants must remain unnamed, but all are in the Northwestern nited States.

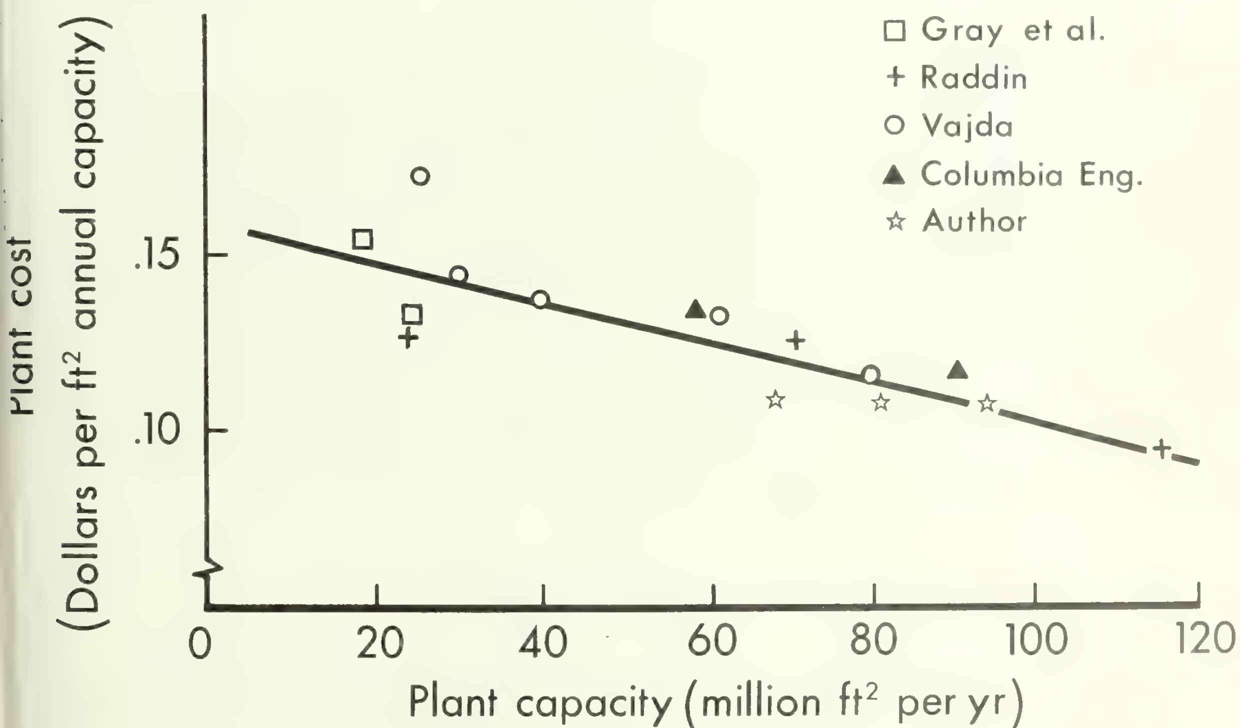


Figure 6.--Particleboard capital costs according to annual plant capacity.

The various estimates obtained were made over a time interval of 10 years, so all were converted to 1973 dollars by use of the implicit price deflator for producers' durable equipment as published in the *Survey of Current Business*.

Capital Cost Estimates

The various capital cost estimates have been converted from total plant costs to cost per square foot of annual capacity, and are shown on figure 6. There is a definit relationship between the capital cost and the size of the plant. Single linear regression was used to fit the line of figure 6, and shows a correlation of -0.88 between plant size and cost. Using this cost relationship, we can construct the following tabulation of expected costs:

Plant size [illegible]	*Expected cost per square foot of annual capacity* (1973 dollars)	*Total capital cost* (1973 dollars)	*Standard error of estimate* (1973 dollars)
40	.137	5,480,000	±432,000
60	.126	7,560,000	±642,000
80	.114	9,120,000	±864,000
90	.108	9,720,000	±990,000

The standard error shown in the last column is one standard deviation from the estimated regression line, so that we could expect about a two-thirds chance that the total cost of an actual plant of the size shown would be within the standard error. One million dollars looks like a very large possible error, but it cannot be reduced without fixing all of the variables of plant location, exact process, and product specification. For this study, where all of these things must be assumed, the standard error is well within the errors of the other estimates that must be made.

These data include several MDF plants in addition to ordinary particleboard plants. If the MDF plants are excluded, virtually the same results are obtained in the regression analysis. It appears that MDF plants cost about the same as particleboard plants, although some of the costs for individual equipment are quite different.

An economic life of 10 years will be assumed for the entire capital investment. This is a rough average, for some of the equipment will be depreciated much faster or slower. Ten years is the most commonly used estimated life in the various published feasibility studies. It represents an estimate of the expected economic life of the plant rather than the physical life. Major equipment, such as the press or forming line, will surely have a physical life much beyond 10 years, but because of technological advance will probably become uneconomical to operate well before being worn out. The cost of the land cannot be depreciated, but because it represents less than 1 percent of the total capital cost it has not been separated from the other investments.

Operating Cost Estimates

The operating expenses are divided for analysis into the costs of material, which will vary directly with the volume of production; variable operating expenses such as labor, which will be partially dependent on volume; and fixed operating costs, which depend primarily on plant size.

Material Costs

Particleboard contains only three materials: wood particles, resin binder, and a ax emulsion to control moisture absorption. There are no significant indirect materals, such as water or processing chemicals, consumed in the production process.

Actual prices paid for dry mill waste materials are difficult to obtain, as this s generally considered to be confidential information; but most plants expect to pay bout $6 per ton, dry weight, for shavings. This price has been stable for some ime and does not change as much as does the price of particleboard. Apparently it is he price necessary to induce the mills to collect dry mill wastes separately from ther wastes and to provide loading facilities. Of equal importance to the price aid for material is the cost of transporting it to the manufacturing plant. Transortation is nearly always by truck. Even though large volumes are often involved, ail transport is seldom used, primarily because of difficulty in unloading. Most oard mills have equipment to dump shavings by tipping the truck or trailer, but have o facilities for unloading railcars.

The cost of transportation will vary by distance traveled and by the amount of ime taken loading and unloading. For short hauls, the usual rig is a tractor-trailer ith a capacity of 17 units, or 20.4 tons dry weight. Longer hauls generally use a ruck-trailer combination with a capacity of 23 units, or 27.6 tons. Approximate osts, which will vary somewhat with the type of road and the speed of the unloading quipment, are:

	Truck-trailer	*Tractor-trailer*
Turnaround time, each end	1/2 hour	1/4 hour
Turnaround cost per ton (1973 dollars)	$0.72	$0.50
Transport cost (1973 dollars)	$0.036 per ton per mile	$0.05 per ton per mile

The break-even point between the two methods is about 15 miles. The total transprtation cost, of course, depends on the length of haul, which cannot be accurately etermined without actually selecting a plant site and determining the distances to ppliers. Board plants will be located close to concentrations of material, but veral cases were found in which significant amounts of shavings were hauled over 0 miles. If we assume that 75 percent of the material will be at an average distance 20 miles, and will be moved by tractor-trailer and 25 percent will be at an avere distance of 100 miles, to be moved by truck-trailer, the following costs (in 1973 dllars) result:

Short hauls: ($0.50) + (20)(0.05) = $0.50 + $1.00 = $1.50/ton

Long hauls: ($0.72) + (100)(0.036) = 0.72 + $3.60 = $4.32/ton

Average cost: (0.75)($1.50) + 0.25($4.32) = $2.20/ton

The costs of resin and wax emulsion are extremely volatile and are rising sharply, a are the costs of all petroleum-based chemicals. During the early summer of 1973, t average prices were $0.075 per pound for urea-formaldehyde resin, and $0.05 per pund for wax emulsion, based on the weight of solids. (Both are produced and used as a liquid.) Average usage is 6 percent resin and 1 percent wax.

To convert these costs to dollars per 1,000 ft^2 of particleboard, a conversion of 1.5 tons of wood per 1,000 ft^2 is used. This allows for some shrinkage from trim and sanding, as the finished 45-pound density board weighs 2,812 pounds per 1,000 ft^2. The total direct material costs per 1,000 ft^2, 3/4-inch basis, (1973 dollars), are:

Wood cost	$ 9.00
Transportation	3.30
Resin	13.20
Wax	1.50
Total	$27.00

Labor Costs

Estimated manning per three-shift day and the average costs (at 1973 rates) are shown in table 2 for 60 and 90 million ft^2 plants. The actual number on the payroll will be one-third more than shown, to allow for manning during weekends and vacations. In assigning average wage rates, the jobs have been classed as either skilled labor or supervisory/maintenance. The rates shown are representative rates for comparable jobs in wood processing in the western Montana area. Averages used are $3.75 plus $1.15 for fringe benefits and vacation for skilled labor and $4.25 plus $1.25 for foremen and maintenance men.

As with the capital costs, there are obvious economies of scale in the cost of labor for larger plants. Particleboard manufacturing is highly mechanized, with many segments of the operation approaching full automation. The function of most of the process operators is primarily to oversee the operation of each segment and make occasional corrections. It takes no more men to watch a large machine than a small one. Only in the material handling and shipping functions do we find a direct relationship between volume and labor.

Energy Costs

Particleboard production requires large amounts of electrical power, primarily in the refining and the pressing operations. In both of these operations power usage is directly related to the volume of production. Power usage, estimated from the three operating plants surveyed and one detailed feasibility study, averages 250 kilowatt hour (kwh) per 1,000 ft^2 of 3/4-inch particleboard. Prices paid for power show considerable variation, depending on the location and the utility providing the service. In Montana, the estimated charge is $0.011 per kwh including demand charges (estimated from Public Service Commission of Montana, Sheet No. Gs-72, October 1972). The total power cost is estimated as $2.75 per 1,000 ft^2 of particleboard.

In all plants surveyed, natural gas, or propane when natural gas is not available, is used for drying the wood particles after they have passed through the refining process. Although gas is used in nearly all dryers, the survey revealed widespread interest in developing alternate heat sources such as sander dust or hog fuel. Many plants are likely to be cut off from natural gas supplies during each winter. Propane is easily substituted, but is more expensive and may be even more difficult to obtain than natural gas.

The most attractive substitute for natural gas appears to be a heat exchanger in the dryer to utilize the heat from process steam. Such a system would substantially add to the cost of the dryer, and could still require some gas to finish the drying and to allow for the necessary fast control, but would markedly reduce the demand for gas.

Table 2.--*Estimates of labor costs in particleboard plants in the Northern Rocky Mountain region, 1973*

Operation	Labor rate per hour[1]	Number of workers per day — Plant size: 60 million ft^2	90 million ft^2
ard	$4.90	5	5
illing & drying	4.90	3	3
lending	4.90	3	3
orming	4.90	3	3
ressing	4.90	3	3.
inishing	4.90	11	12
aterial handling	4.90	5	8
leanup & helpers	4.90	18	22
oiler	4.90	3	3
aboratory	4.90	3	3
hift millwright	5.50	3	3
hift electrician	5.50	3	3
nife grinder	4.90	2	3
hipping	4.90	8	12
oreman	5.50	3	3
aintenance foreman	5.50	1	1
aintenance millwright	5.50	1	2
aintenance electrician	5.50	1	1
aintenance helper	4.90	1	2
Total workers per day		80	95
Labor cost per day		$3,193	$3,786
Labor cost per year (350 days)		$1,117,550	$1,325,100
Cost per 1,000 ft^2		$18.50	$14.72

Source: Manning tables provided by Columbia Engineering International, Vancouver, B.C. Average wages calculated from contracts provided by the Missoula County Trades & Labor Council, Missoula, Montana.

[1] Includes wages plus fringe benefits.

Current usage of natural gas is about 1,500 ft^3 per 1,000 ft^2 of particleboard production. The usage rate varies, depending on the weather and the moisture of the wood particles. Shavings, which make up the bulk of the furnish, are normally quite dry, and passing chips through the dryer serves mainly to maintain a uniform moisture content rather than actually to dry them. Wetter-than-usual wood or a humid day can easily double or triple the usual gas demand.

Gas prices also vary, depending on location. Using western Montana gas prices of $0.48 per 1,000 ft^3 as a norm, the cost for drying will be $0.72 per 1,000 ft^2 of particleboard production at 1973 prices. With uncertainties about supply and the possibility of rapid price increases, this figure could easily double within the next year.

Particleboard production requires steam for heating the press, for building heat and, in the case of MDF plants, for heating and softening the wood particles. Older plants generate steam from natural gas or other fossil fuels, but nearly all newer installations have boilers fired with sanderdust, a very fine mixture of wood and resin collected in filter systems. Sanderdust presented a serious disposal problem until the introduction of boilers designed to burn it. The dust makes a very clean and easily handled fuel. The production of sanderdust and the demand for steam seem to be nicely balanced, with most plants burning all of their dust and using most of the steam produced.

The cost of installing the boiler has been included as a part of the total capital cost, and once it is installed the operating costs will be small, so that no extra cost for steam has been included in the cost analysis.

Total Costs

The estimated annual administrative and overhead expenses are \$4.50 per 1,000 ft^2 for a 60 million ft^2 particleboard plant and \$3.53 per 1,000 ft^2 for a 90 million ft^2 plant (table 3). When these costs are added to materials, fuel, labor, and other costs, the total expected production costs for a particleboard plant in the Northern Rockies are \$70.98 per 1,000 ft^2 for a 60 million ft^2 plant and \$64.06 per 1,000 ft^2 for a 90 million ft^2 plant (table 4).

Table 3.--*Estimated annual administrative and overhead expenses of a particleboard plant in the Northern Rocky Mountain region, 1973*

	Plant capacity	
	60 million ft^2	90 million ft^2
Salaries, including payroll costs:		
Plant manager	\$ 25,000	\$ 28,000
Plant superintendent	18,000	19,000
Technical director	15,000	15,000
Bookkeeper	12,000	12,000
Clerk/Stenographer	18,000 (2)	27,000 (3)
Shipping clerk	12,000	12,000
	\$100,000	\$113,000
Insurance	40,000	50,000
Property taxes	70,000	90,000
Office expenses	60,000	65,000
	\$ 27,000	\$318,000
Overhead per 1,000 ft^2	\$4.50	\$3.53

Table 4.--*Summary of expected production costs of a particleboard plant in the Northern Rocky Mountain region, 1973 (per 1,000 ft², 3/4-inch basis)*

	Plant capacity	
	60 million ft^2	90 million ft^2
Wood	$12.30	$12.30
Resin	13.20	13.20
Wax	1.50	1.50
Power	2.75	2.75
Fuel (gas)	.72	.72
Labor	18.63	14.72
Maintenance and supplies	2.00	2.00
Overhead expense	4.50	3.53
Operating contingency (5%)	2.78	2.54
Subtotal	$58.38	$53.26
Reserve for depreciation (10-year straight line)	12.60	10.80
Total	$70.98	$64.06

PRODUCT MIX, PRICES, AND NET RETURN TO MILL

Few established particleboard plants produce only one type of board, and all of them produce a variety of thicknesses. Most new plants have been aimed at the industrial board markets, where profits are generally higher than for nonindustrial board types. Unfortunately, there are no reliable estimates of prices for industrial grade boards, primarily because the product class includes many special varieties and may include much secondary processing.

Whatever the final market goal, there seems to be a tendency for new plants to produce underlayment particleboard, and to move into the industrial market after they are well established. Underlayment is less exacting to manufacture than industrial board and has a ready market that requires less sales effort. The following analysis will consider only underlayment grades, because any new plant will likely be forced to exist for the first several years without any substantial industrial grade production. The capital costs of a new plant that were developed earlier (fig. 6) were based on the presumption that the plant would have equipment suitable for industrial board. It is assumed here that the industrial grade capabilities will not be utilized in the early years, so that the plant must prove profitable on underlayment alone. A plant built to make underlayment only would cost significantly less.

All summary statistics for the particleboard industry are reported on the basis of 1,000 ft^2 of board 3/4-inch thick. However, very little underlayment grade is actually three-fourths inch; most is five-eighths inch or less. Underlayment production in 1972, as reported by the U.S. Department of Commerce, included the following sizes:

Thickness *(Inch)*	*Quantity* *(Million ft^2)*	*Production percentage* *(Percent)*
5/8	643	68
1/2	130	14
other (mostly 3/8)	167	18
Total	940	100

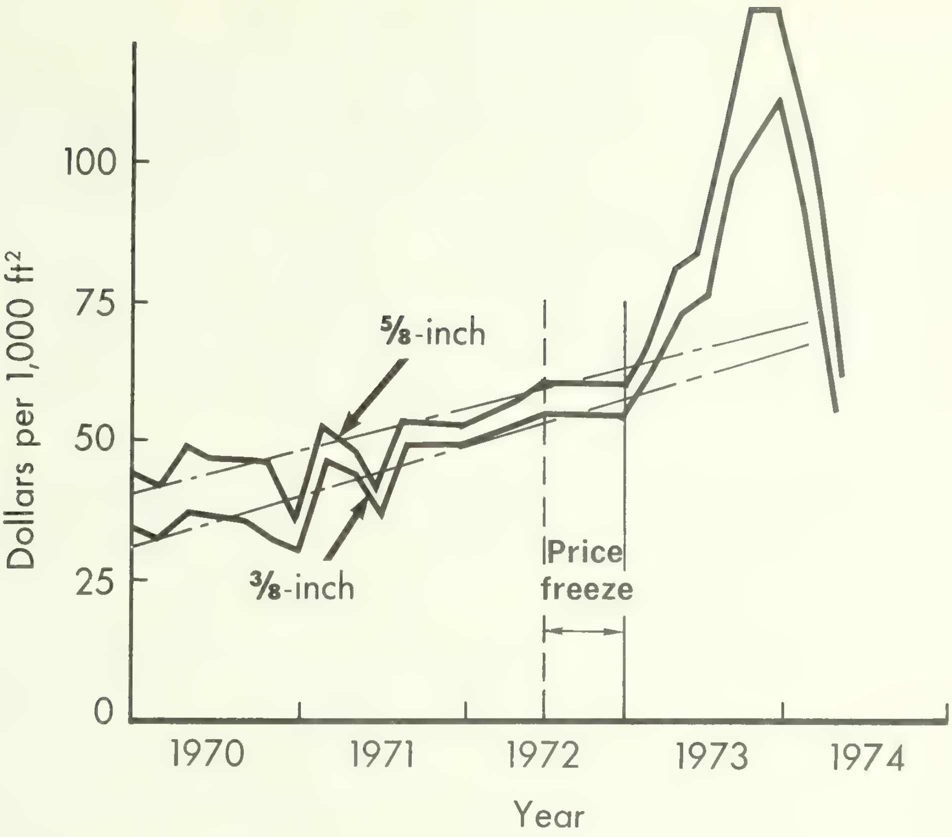


Figure 7.--Particleboard prices; western underlayment, f.o.b. west coast. Source: Crows Plywood Newsletter 1970-1974.

It is assumed that the typical plant will produce in this ratio, so that weighted erages of the prices can be converted to an expected price on a 3/4-inch basis.

Particleboard Prices

Prices for western particleboard are published every Friday, based on average ices f.o.b. West Coast. The data are both complete and accurate. We can easily see at prices have been, but predicting future prices is another matter. Like the prices other wood products, particleboard prices have been subject to severe fluctuations, that any long-term projections will be influenced very heavily by what one chooses the base period from which to forecast.

Bimonthly prices for 3/8- and 5/8-inch particleboard since January 1970 are shown on gure 7. Prices for 1/2-inch particleboard lie between the two but have been omitted r clarity. The time series was started in 1970 because prices have been quite stable om 1970 until mid-1973. A very different picture would emerge if 1969 were included. ing 1969 the price of 5/8-inch board rose to a high of $120 before plunging to the shown at the beginning of 1970.

The capital and operating costs estimated in the previous sections were all verted to 1973 dollars, so that the price estimates for board sales should also be 1973. Because we have prices for all of 1973 it is tempting to simply calculate average for the year. A simple average may be very misleading, however, because of effects of the price freeze during the latter half of 1972.

Particleboard prices were frozen in July of 1972 (at $58 for 5/8-inch board) follo ing a 2-year period of steadily rising prices. The freeze extended until the end of January 1973. During the period of the freeze, demand was heavy and production fell well behind demand. When the freeze was lifted, producers had large backlogs of unfilled orders and demand was still strong; as a result, prices shot upward. Prices increased steadily to $130 at the end of November 1973, stabilized for a short while, then dropped sharply starting in February 1974.

Particleboard prices since the start of the price freeze in mid-1972 are extraordinary, and should not be used to predict the economic feasibility of particleboard manufacturing in the future. We need an estimate of prices had there been no price freeze. The two dashed lines on figure 7 are linear extensions of the prices from January 1970 through June 1972. Extending these trends into 1973, we can estimate the following prices:

Board thickness (*Inch*)	*Projected price* (*Dollars*)	*Equivalent price, 3/4-inch* (*Dollars*)	*Percentage of total sales* (*Percent*)
5/8	67	80.4	68
1/2	65	97.5	14
3/8	62	124.0	18

(Weighted average price, 3/4-inch basis: $90.64)

These price estimates exclude both the short period of high prices in 1969, and the abnormal period of the price freeze and subsequent price "bubble." This selection of a time period of low, stable prices as the forecast base means that the price estimates are conservative. There may be short-term fluctuations of prices below the estimate, but we can reasonably take the prices shown above as a minimum expected price.

Basing the expected profitability of a plant on minimum prices will yield pessimistic results, so that we should also establish an upper range for the expected sales price. We cannot, however, use the same technique as used for establishing a low range; that is, we cannot select a period of stable high price as a forecast base, because there have been no such periods. There have been high price periods, but they were too unstable to serve as a forecasting base. Attempts were made to find correlations between the price of particleboard and indicators such as gross national product, housing starts, and plywood prices. The results were disappointing. No useful indicator with significant predictive ability was found. The price of plywood has good correlation with the price of particleboard, but since the two tend to be coincident, plywood price is not useful as an indicator of particleboard price.

A high price range 25 percent above the minimum will be used to examine the effect of higher sales prices on the profitability of particleboard manufacture. In view of the very large fluctuation in prices over the past 5 years, a price 25 percent above the minimum is well within the range of possibility. The correct figure is probably somewhere between the two.

The prices shown in figure 7 have already been adjusted for trade and price discounts (5 and 3 percent), but do not include freight charges. Any differences between actual freight cost and the cost from the west coast would show as an effective difference in total price. Freight charges of course depend on the origin and destination, but plants in the Northwestern Rocky Mountain region can expect to enjoy an advantage of about $2 per 1,000 ft^2 over west coast shipments to the Midwest or east coast. This difference will appear as a higher effective sales price at the mill.

Rate of Return on Investment

The expected costs and incomes developed in the previous section have been ımmarized in tables 5 and 6, which also show the expected first-year rate of return ı the original investment.

Table 5 is based on the low price estimate, which averages \$90.60 per 1,000 ft^2 ı a 3/4-inch basis. At this price, the estimated first-year return of 9 and 12 per- ent for the two plant sizes would be acceptable for an operating plant but would robably not be high enough to induce new plant construction. It should be noted that ıe first-year return on investment is in itself a very conservative method of viewing ıe value of an investment. The actual return will rise each year as the plant and quipment are depreciated. The internal rate of return over the 10-year life is 16 ercent instead of 9 percent for the 60 million-ft^2 plant.

Table 6 presents the return at a sales price 25 percent higher than table 5, or 113.25 per 1,000 ft^2, 3/4-inch basis. At this price the first-year return on invest- ent nearly doubles for both sizes of plant, to 18.4 and 21.6 percent. The returns ıown in these two tables represent the pessimistic and optimistic extremes that can be cpected. The true return on investment is probably somewhere between the two.

First-year returns of about 15 to 20 percent should be sufficient to attract ıpital to the industry, so that we can expect to see continued growth of particle- oard production in the Northern Rocky Mountain region.

Table 5.--*Low price estimate: expected return on investment for millwaste particleboard*

Return factors	Plant size: 60 million ft^2	Plant size: 90 million ft^2
les price per 1,000 ft^2		
3/4-inch basis	\$ 90.60	\$ 90.60
Plus freight advantage	2.00	2.00
Net price to mill	\$ 92.60	\$ 92.60
t of production[1]	70.98	64.06
income per 1,000 ft^2	\$ 21.62	\$ 28.54
able income per year	\$1,297,200.00	\$2,568,600.00
ncome tax (6-1/2% State, 48% Federal)	706,974.00	1,399,887.00
income per year	\$ 590,226.00	\$1,168,713.00
rginal investment	\$6,560,000.00	\$9,720,000.00
ist-year return on investment (%)	9.0	12.0

[1]From table 4.

Table 6.--*High price estimate: expected return on investment for mill waste particleboard*

Return factors	Plant size: 60 million ft²	Plant size: 90 million ft²
Sales price per 1,000 ft²		
3/4-inch basis	$ 113.25	$ 113.25
Plus freight advantage	2.00	2.00
Net price to mill	$ 115.25	$ 115.25
Cost of production[1]	70.98	64.06
Net income per 1,000 ft²	$ 44.27	$ 51.19
Taxable income per year	$2,656,200.00	$4,607,100.00
Income tax (6-1/2% State, 48% Federal)	1,447,630.00	2,510,870.00
Net income per year	$1,208,570.00	$2,096,230.00
Original investment	$6,560,000.00	$9,720,000.00
First-year return on investment (%)	18.4	21.6

[1]From table 4.

ROUNDWOOD AND FOREST RESIDUE FURNISH

The preceding cost analysis was based on the assumption that the bulk of the raw aterial for any new particleboard plant would be fine mill wastes. As long as there re adequate supplies of these mill wastes in the Nation, we can expect that there ill be no major usage of other materials (with the exception of some structural board ade from roundwood).

As mill wastes become more fully utilized, there will be a trend toward the use f roundwood and wastewood now left in the woods. It must again be emphasized, owever, that uncommitted mill waste supplies should be available for another 3 or 4 ears, and that the question of plant location cannot be viewed from a local point of iew. As supplies of mill wastes are exhausted in a sector such as the South or the orthwest, we cannot expect that additional particleboard manufacture in those areas ill be forced to roundwood supplies. Instead, production expansion in those areas ill cease and will be shifted to areas that still have cheap materials. Only after ne nationwide supplies of mill wastes are largely committed will there be a signifi- ant shift to other furnish material.

The first large-scale use of forest residues should come in those areas that are ose to large markets and have large supplies of residue materials. Because most eas (except the Plains States) have plentiful forest residues, closeness to market ould be the prime factor in determining plant location. Therefore, basing our dgment on the location of residues and markets, we might expect the first move of pansion to be in the Northeast followed by the South and northern California, then e Rocky Mountains, and finally the Pacific Northwest. Besides materials and markets, wever, there are a number of other factors to be considered which may alter the tterns.

The Northeast

There are large quantities of wood residue and small roundwood available in the Northeast, mostly in mixed hardwood species (USDA Forest Service 1973). With major markets nearby, the area would seem a natural for board manufacture. There are several factors which will slow development in this area, however. The mixed hardwood species available in the Northeast will make good board, but are much more difficult to work with than softwood. Most expansion will probably be in MDF plants, since the MDF process accepts hardwood more readily than a standard particleboard process.

Although there are large quantities of hardwood forest residues, the material is much more scattered than the residues in the softwood regions. Ownership is mostly private and often scattered among small holdings. Most harvesting and processing operations are small, so that collection of residue will be difficult and costly. Particleboard manufacture requires a reliable source of large quantities of material. Plants in the Northeast could not rely on residues for a steady supply, and would be forced to use specially cut roundwood, which would substantially increase the cost of material. It is unlikely that the transportation savings of about \$50 per 1,000 ft^2 of particleboard over west coast plants would be enough to offset the increased wood costs. Eastern plants would be at an additional disadvantage with higher construction costs, higher wages, and much higher energy costs.

The South

The South also has large quantities of unused residues, and although the supply there also is somewhat scattered among small operations, there appears to be a strong trend toward larger concentrations. Both softwoods (pine) and hardwoods are available. With its close proximity to major markets and large dependable supplies of residues, the South will likely be one of the first areas to go into large-scale utilization of forest residues for particleboard.

Northern California

Northern California has a large nearby market in the Southwest, and vast quantities of forest residues. In addition, the residues produced in logging are concentrated because of the dense timber stands and large-scale logging operations. Everything appears ideal for utilization of forest residues except that there are still unused mill wastes available for particleboard production. The forest residues will not be used until all mill wastes are committed, which may take 3 or 4 years. Once the mill wastes are gone, however, the use of forest residues in California should proceed rapidly.

Rocky Mountains

In addition to logging residues, the Northern Rocky Mountain areas have large tracts of dead timber that would be suitable for particleboard. Collection of forest residue materials, however, will be more difficult and expensive than in the South or along the Pacific Coast. Rugged terrain, severe winters, and lower density stands that require collection over greater areas will make residue use less feasible in the Rockies than it will be in the South or Far West. These disadvantages will be somewhat offset by slightly lower operating costs for labor and energy, and by some advantage over the West Coast on transportation cost.

The Pacific Northwest

Oregon and Washington appear to be unlikely locations for forest residue uses because of the greater distance to markets. Three factors favor this region, however: the high density of forest residues, the species available, and the existing concentrations of particleboard manufacturing plants.

The dense stands of timber along the Pacific Coast produce equally dense concentrations of forest residues, especially logging residues. Heavy concentrations, along with the mild climate that allows year-round work, will result in easier and cheaper collection of forest residues.

The species mix of mostly Douglas-fir and ponderosa pine also favor expansion of west coast production. Although nearly any wood fiber will make a decent board, it has been found that these species are two of the easiest to work with.

Finally, the existing concentrations of particleboard manufacturing in Oregon should not be overlooked. There are subtle advantages in locating close to others in the same industry. Interchange of ideas, help with mutual problems, and the growth of adequate services all come from industry concentrations. So long as nearby plants are not forced to compete for limited raw materials, the concentration is desirable; and for plants designed to operate on forest residues, there is enough for all for many years to come.

Effects of Structural Board

As mentioned earlier, structural particleboard is not expected to be a major factor in the industry before about 1980, at which time there may be as many as 10 plants in the United States. The early growth will almost surely be based on aspen roundwood, and will be located in the North Central States, because that is the site of initial development. Later expansion, however, will probably be based on utilization of forest residues. Mill wastes are not really suitable for structural board and will, at any rate, be mostly committed to other uses. Forest residues appear to be a natural furnish for structural board. As with other panel products, the South has a definite advantage, with ample wood supplies and short hauls to markets. The first big growth in structural board manufacturing in the late 1970's and early 1980's probably will occur there.

The Northwest and Rocky Mountain States appear to be on the bottom rung as far as structural board is concerned. Except for the two or three plants supplying the California and local markets, the freight disadvantage of \$50 to \$60 per 1,000 ft^2 will be a strong deterrent to rapid growth. The Northwest may have one advantage: the superior physical characteristic of the species available. Douglas-fir in particular is a very strong, easily worked wood. It may be that a superior board could be manufactured in the Northwest at some savings in operating cost over the South or Midwest. The higher strength of the western softwood may also allow a significant decrease in the amount of resin required. At present prices, the cost of the phenolic resin amounts to about 10 to 15 percent of the manufacturing cost of the board. With resin prices expected to rise even more rapidly than those of other commodities, a saving in resin could be quite significant by 1980.

MANUFACTURING COST: MILL WASTE VS. FOREST RESIDUE

Disposing of forest residues, especially those created by logging, is a growing problem, and the manufacture of particleboard would seem to be a good solution. As indicated earlier, however, roundwood is less desirable than mill waste for standard particleboard or medium density fiberboard because of lower costs and ease of handling for mill waste. On the other hand, some of the added costs of using forest residues may be offset by the value of cleaning up the forest floor. In this section we will attempt to estimate the cost differences between using forest residues and dry mill wastes.

Collection of Residues

Forest residues may be loaded on trucks and hauled intact to the processing plants, or may be reduced to chips in the field. The choice of technique will depend on the nature of the residues and the type of terrain. Large residues consisting primarily of cull logs in rugged terrain with poor roads can best be handled whole by the same equipment used for sawlogs. Small or irregularly shaped residues located in easily accessible areas can more easily be chipped on site and hauled to the processing plants in chip trucks.

Whatever method of collection is used, one of the most significant differences between forest residues and dry mill wastes--bark--must be dealt with. The effects of bark in particleboard are difficult to explain. Since most particleboard is made from mill wastes that contain no bark, there is generally no bark in particleboard. It is possible, however, to use up to about 10 percent bark in the board without serious change in the physical characteristics. About 2 years ago a large west coast producer did just that, even advertising in trade journals that the addition of the bark did not change the board, allowed lower prices, and helped solve the bark disposal problem, all of which was quite true. The customers would not accept the board. Although the bark did not affect the physical properties of the board, it was very visible even in small quantities, as it has a much darker color than the wood particles. Since most particleboard is covered by floor coverings, overlays, or paint, it is difficult to explain this reaction, but it was firm. The producer had trouble getting rid of the "bark board" and rebuilding his reputation for producing a quality board. This episode is well known in the board industry, and other producers will have nothing to do with utilizing bark.

Any forest residue collection system must provide for bark removal, which may eliminate some types of residues as a possible source of particleboard furnish. Although barking and chipping equipment is available (Host and Lowery 1970), good cost estimates were not found because the great variability of residues makes any generalized estimate meaningless. No attempt will be made to estimate the cost of collecting, debarking and chipping, and transporting residues to the plant site.

Once the chipped residues are delivered, there are still differences in the cost of processing between residues and dry mill waste.

Operating Cost Differences

The processing of chipped forest residues will differ from the processing of dry mill wastes up to the point that the particles are refined to the desired size and shape and are dried; from then on there will be no differences. Cost differences will exist, then, in raw material storage, refining, and drying.

It is expected that a plant operating on chipped forest residues will maintain a much larger inventory of raw material than it would if it were using mill waste, especially if the residues are located in mountainous country. Collection of forest residues cannot be relied upon as a steady source of material. Many forests will be inaccessible in the winter, and dry summers may cause closure because of fire danger. Supplies of mill wastes do not fluctuate because sawmills maintain an inventory of logs, but a particleboard plant operating on forest residues would need its own large inventory.

Inventories of dry mill waste vary greatly, from enough material to last 5 days (in Oregon) to about 2 months (in Montana). The very small inventories of raw material found in all Oregon plants are primarily due to an Oregon law requiring inside storage for all dry mill wastes to avoid air pollution from particles and dust. Even a 5-day supply requires a very large building or silo. The small inventories are tolerable because of the closeness of the sources and the generally mild weather, which rarely stops the chip trucks. In Montana outdoor storage is allowed, and the possibility of severe storms which will stop the supply of mill waste dictates a buildup of about a 2-month supply of materials.

Chipped residues will be stored outside, and the average plant will have about a 5-month supply. Capital costs will be increased because of the extra storage space required. An extra 4 acres, at $6,000 per acre (with improvements) is estimated. Of more importance is the extra investment in inventory. At a value of $8 per ton, a 5-month supply for a plant of 90 million ft^2 annual capacity represents an investment of about $600,000. The extra land and inventories do not depreciate, but will add substantially to the capital investment and working capital requirements. At an interest charge of 10 percent, these added investments amount to $62,000 per year, or an additional cost of $0.69 per 1,000 ft^2.

The milling and drying of chipped residues will require more equipment and will cost more than mill waste. The chips are both larger and wetter than mill waste, and so will pass more slowly through the refiners and dryers. It is estimated that a 90 million ft^2 plant will require two extra refiners at $50,000 each, and one extra dryer, at $60,000 (1973 prices). With a 10-year depreciation and at 10 percent interest, the added capital cost is about $26,000 per year, or $0.29 per 1,000 ft^2.

Additional energy for refining and drying is expected to add 50 percent to the electrical power requirements and to double the gas requirement. The added energy costs per 1,000 ft^2 are $2.10 (at 1973 prices).

The total added cost for forest residue furnish, then, is $3.08 per 1,000 ft^2 of particleboard: $0.69 for increased investment in storage facilities and inventory; $0.29 for additional equipment; and $2.10 for energy. At 1-1/2 tons of wood per 1,000 ft^2, the added cost is about $2 per ton. To be competitive, then, forest residues must be debarked, chipped, and delivered to the plant site for about $2 per ton less than dry mill waste, or for about $6 per ton. The transportation cost alone is likely to be close to the $6 per ton value of the chips, so that collecting, debarking, and chipping costs would need to be almost zero for forest residues to compete successfully with mill waste as a raw material for particleboard.

PARTICLEBOARD LOCATIONS IN THE NORTHERN ROCKIES

The Northern Rocky Mountain region currently has two operating particleboard plants: Tenex at Sandpoint, Idaho, and Evans Products at Missoula, Mont. Plum Creek Lumber has built and is just starting operation of a new MDF plant in Columbia Falls, Mont., and Champion-International has announced plans to build a plant near Missoula. The industry is moving rapidly into this region and we can expect further rapid growth.

The new plants will be located close to large steady sources of mill waste, as long as it lasts. Except for rail service at the plant site, which usually is available wherever there are sawmills, there are no other special requirements for particleboard plants.

Estimates of concentrations of mill wastes may be obtained by noting the location of sawmills and plywood plants. Table 7 summarizes sawmill and plywood output in 1972, as reported by the *Forest Industries* annual survey (Lambert 1973). This survey is known to be incomplete, but does include most of the larger mills and is sufficient for locating concentrations of mill waste. The region has been divided into 10 areas, primarily by major watershed. Roads tend to follow the major valleys, so that movement of mill wastes would be much easier along rivers than between river systems.

Table 7.--*Northern Rocky Mountain mill waste estimate, 1972*

Type of mill waste		Location of mill or plywood plant								
		Kootenai	Flathead	Lower Clark Fork	Upper Clark Fork	East side Montana	Coeur d'Alene	Clearwater	Lower Snake	Upper Snake
Sawmill production (million bd ft)	(1)	312	340	162	251	89	560	510	449	145
Production by mills over 20 million bd ft/yr	(2)	305	307	162	245	0	463	435	439	110
Chips (1,000 tons)	(3)	157	158	84	126	0	239	224	227	57
Sawdust (1,000 tons)	(4)	80	81	43	65	0	122	115	156	29
Shavings (1,000 tons)	(5)	58	59	31	47	0	89	84	84	21
Plywood production (million ft^2)	(6)	70	215		210		145	300		
Green chips (1,000 tons)	(7)	24	74		73		50	104		
Dry trim (1,000 tons)	(8)	6	19		18		13	26		
Total green chips (1,000 tons)	(9)	181	232	84	199	0	289	238	227	57
Total fine wastes (1,000 tons)	(10)	144	159	74	130		224	225	240	50
Already committed to particleboard (1,000 tons)	(11)		120		135		30			
Unused fine wastes (1,000 tons)	(12)	144	39	74			194	225	240	50

Production of all reporting mills is shown in the first line, and the total production from mills which produced 20 million bd. ft. or more during 1972 is on the second. On the assumption that mill waste will be available only from the larger mills, the lower figure has been used to estimate the amounts available. The amount of residues generated by lumber and plywood production has been estimated by use of the following conversion factors, which were developed from surveys of Oregon mills (Manock and others 1970).

Residues from lumber production in dry tons of waste per 1,000 bd. ft.:

	Conversion Factor
Coarse residues	
Suitable for pulp chips	0.516
Sawdust	.264
Planer shavings	.192

Residues from plywood production in dry tons of waste per 1,000 ft^2 (3/8-inch basis):

	Conversion Factor
Coarse residues	
Suitable for pulp chips	.346
Dry trim	.088

Lines 9 and 10 in table 7 shows the total pulp chips and total dry mill waste generated in each area. Particleboard production would be based primarily on the fine wastes, but could use pulp chips. Line 11 gives the approximate amount of mill waste already committed to the particleboard plants at Columbia Falls and Missoula, Mont., and at Sandpoint, Idaho. The proposed Champion-International plant at Bonner is not shown, as its size is unknown. Its inclusion would appear to overcommit the supplies in the upper Clark Fork area, but it should be noted that the Bonner sawmill and plywood plant were not reported in the 1972 survey, as they were not producing then.

The typical new particleboard plant can be expected to be designed for an annual capacity of about 60 to 100 million ft^2 which would require 90,000 to 150,000 tons of wood residue per year. It then appears that there will be sufficient fine mill waste in the Northern Rockies for four or five plants.

In Montana the only uncommitted concentration of mill waste is in the Kootenai Valley around Libby. Unused residues in the Flathead (Kalispell) and the lower Clark Fork (Thompson Falls) areas combined would probably be enough to support a plant, but each area involves long hauls and so would be less desirable than the locations in Idaho.

Three areas in Idaho show definite concentrations. The areas around Coeur d'Alene, the Clearwater drainage (Lewiston or Orofino), and the lower Snake region around McCall or Grangeville all have dry mill wastes of 200,000 tons per year or more.

With these rather large supplies of mill waste available in the Northern Rockies and the shrinking supplies elsewhere in the Nation, we can expect that the particleboard industry will be building here within the near future, and will have most of the mill waste committed to production within the next 5 years.

No attempt will be made to identify specific locations for new plants. Effective transportation and utilities are the most essential requirements for a plant. Good highways for raw material delivery and rail service for finished products are essential, but are widely available throughout the region. Compared to the costs of equipment and operation, any differences in site cost, local taxes, or wage rates among possible sites are negligible.

ECONOMIC AND ENVIRONMENTAL EFFECTS OF PARTICLEBOARD PRODUCTION

From both the economic and environmental viewpoints, a particleboard plant should be a welcome addition to the industrial base of any community.

The most obvious economic effect is the net addition of permanent jobs in the community. A 90 million ft^2 capacity plant will employ about 125 persons for full three-shift operations. Because of the high degree of mechanization of particleboard manufacture, most of these jobs will require skilled labor, and will tend to have higher average wages than other local industries such as lumber mills. Of particular importance is the expected stability of these jobs. The wood products industry tends to be quite cyclical, with occasional large fluctuations in employment. The high capit investment in a particleboard plant makes it uneconomical to follow these fluctuations, so that once a plant is established it will be operated at close to capacity if at all possible. The result will be a steady employment pattern all year long for the life of the plant, which would be for a minimum of 10 years, and probably much longer.

The environmental effects of particleboard manufacture are, on the whole, positive The greatest effect is that fine mill wastes are transformed from a waste material that is usually burned or landfilled into a useful product. A small amount of fine wood dust may be emitted into the atmosphere during production, but the use of a filter system can largely eliminate such problems. Several years ago Oregon instituted very strict requirements for particulate emission from particleboard plants. The Oregon plants have been able to meet these standards, and the cost estimates given earlier include the cost of equipment necessary to meet the Oregon standards.

There is virtually no waste generated by particleboard manufacture, and no obnoxious odors are produced. The only waste generated in manufacturing is sander dust, which is collected and burned as fuel, and scrap particleboard, which is ground and and reused as a raw material. Particleboard manufacture is definitely a clean and desirable industry.

SUMMARY

Growth Projections

Total U.S. demand for particleboard is expected to continue its growth rate of ıbout 16 percent per year. The growth in demand and production will include expansion of underlayment and industrial products and will also include new products such as nedium density fiberboard and structural particleboard. No significant changes in the regional distribution of demand is expected. The forecasted demand for particleboard in the United States is:

Year	*Demand, billion ft² (3/4-inch basis)*
1973	3.6
1974	4.2
1975	4.8
1976	5.5
1977	6.4

xpansion in production capacity will be located close to mill waste supplies until the nill wastes are gone. Two or three new plants each in the South, California, the orthwest, and the Rocky Mountains will exhaust mill waste supplies within the next years. New plants will then use roundwood or forest residues. Favored areas for ew plants will then be the South, the west coast, and the Rocky Mountain regions.

Production Costs and Profits

The investment required for a new particleboard plant will be much the same egardless of location, but will depend on the size of the plant. Larger plants, of ourse, cost more than small ones, but the cost per unit of output is much less for arger plants, so that there is a strong trend toward greater size in new installations. he average size of new particleboard plants is expected to be 90,000 ft^2 of output apacity, at an average capital cost of $10.8 million.

The operating costs are also dependent on plant size, with large plants having a oderate advantage. The total cost of manufacturing particleboard, 1,000 ft^2, 3/4 inch asis, are approximately $64 ($27 for material, $22 for labor and energy, and $15 for apital and overhead).

Particleboard prices have been relatively stable compared to other wood products, but price projections are especially difficult because of the severe distortion caused by the price freeze of 1972. Conservative estimates, which exclude prices since the beginning of the price freeze, yield price estimates of $90 per 1,000 ft^2, 3/4-inch basi At these prices, a new plant in the Northern Rocky Mountain region would have a first-year return on investment of 12 percent. If prices were 25 percent above the conservative estimate, the first-year return would be 22 percent.

Particleboard Production in the Northern Rocky Mountains

There are two operating particleboard plants in the Northern Rocky Mountain region; at Sandpoint, Idaho, and Missoula, Mont. A new medium density fiberboard plant at Columbia Falls, Mont., is just starting production. We can expect several more plants in the next few years, all using mill waste furnish. Estimates of unused mill wastes show concentrations in the Kootenai Valley of Montana and Idaho, and the Ceour d'Alene, Clearwater, and Lower Snake River areas in Idaho. New plants will be located close to the available mill wastes.

Using forest residues in place of mill wastes for particleboard will add about $3 per 1,000 ft^2 to the manufacturing cost, which makes forest residues an unattractive substitute for mill wastes. As unused mill waste becomes scarce within the next 3 to 5 years, however, we can expect that new particleboard plants will be designed to use forest residues. The new plants will be located close to either the large markets or close to heavy concentration of forest residues. The first large-scale users of forest residues will probably be in the South and on the Pacific coast. Because a plant using forest residues, located in the Northern Rocky Mountains, would have no advantage over similar plants in other parts of the country, we should expect that utilization of forest residues for particleboard manufacture in the Rockies will lag behind the rest of the Nation.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1974 — 677-097 / 62 REGION NO. 8

WITHYCOMBE, RICHARD

1975. The outlook for particleboard manufacture in the Northern Rocky Mountain region. USDA For. Serv. Gen. Tech. Rep. INT-21, 39 p. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

National demands for particleboard panel products and raw materials supply are projected for the 1970's. Expanding production is expected to shift raw material sources to forest residues. Analysis of production costs indicates that in the Northern Rocky Mountains plants utilizing forest residues cannot profitably compete with plants utilizing mill residues until existing mill residues are utilized.

OXFORD: 796, 839.84, 862.2
KEYWORDS: particleboard, waste wood uses, production studies, raw materials, wood residues.

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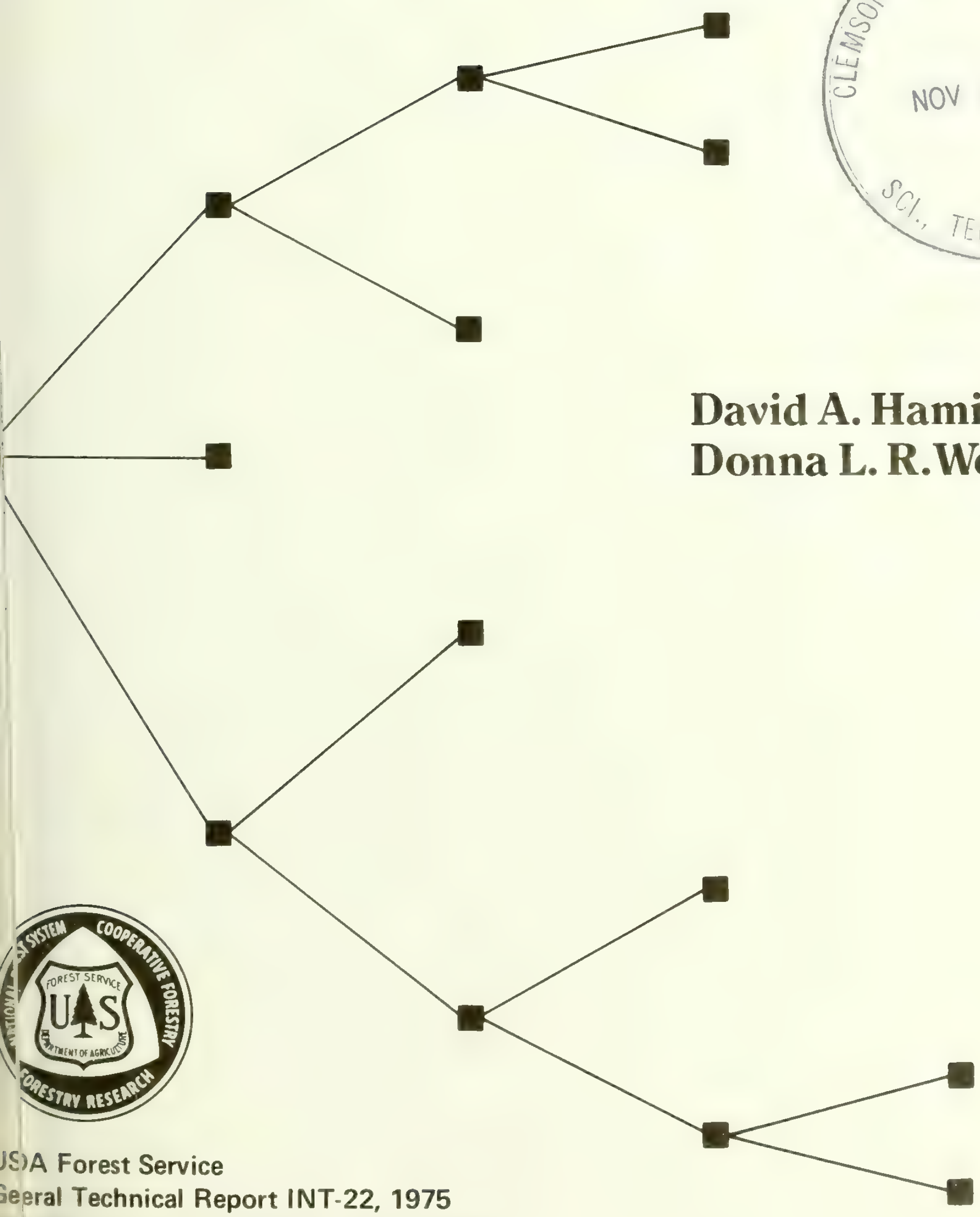
AMERICAN REVOLUTION BICENTENNIAL

GROWING FROM

U.S. FORESTRY

SCREEN: a computer program to identify predictors of dichotomous dependent variables



David A. Hamilton, Jr., and
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USDA Forest Service
General Technical Report INT-22, 1975
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SCREEN: a computer program to identify predictors of dichotomous dependent variables

David A. Hamilton, Jr., and Donna L. R. Wendt

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
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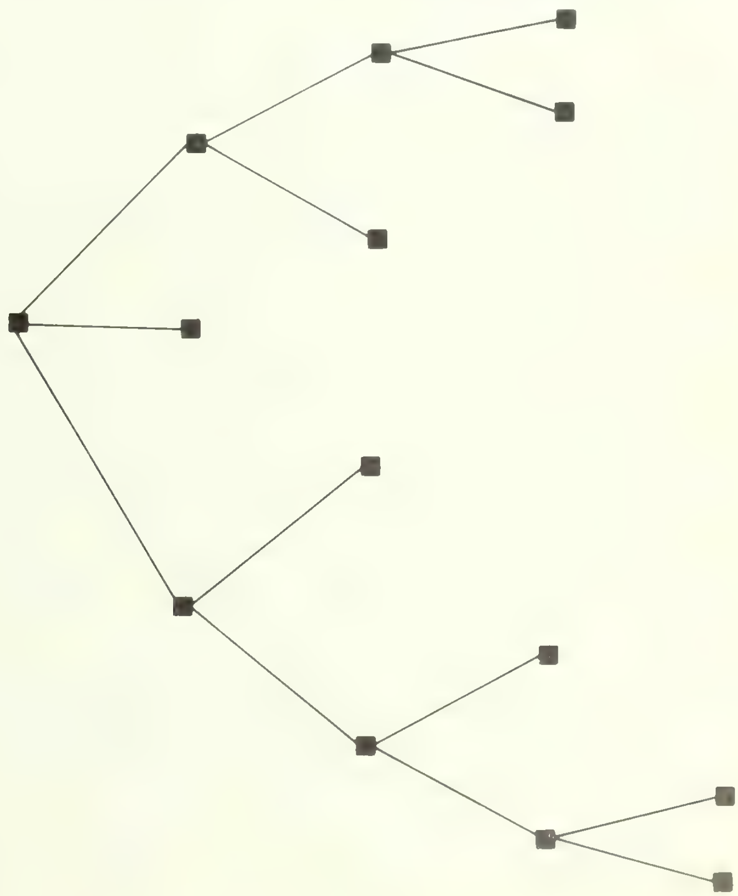
ABSTRACT

The algorithm reported here is a modeling tool that screens potential relationships between a set of independent variables and a dichotomous dependent variable. Uses of the algorithm and its properties are discussed. A user's guide explains the preparation of input cards for the two PL/1 procedures and explains the program output.

INTRODUCTION

The screening algorithm in the computer program SCREEN was designed to aid in the election of that set of independent variables that best predicts the outcome of a ichotomous dependent variable. A dichotomous dependent variable is one for which the esponse is limited to one of two possible outcomes. The algorithm and an example of ts use were discussed by Gleser and Collen (1972). The theory behind the algorithm as presented by Sterling and others (1969). SCREEN consists of two PL/1 procedures: EARCH and GRAPH. SEARCH screens the data for relations between the proportions of the wo possible outcomes of the dependent variable and the explanatory independent varia-les. GRAPH then prints the results of this screening in a format similar to a decision tree."

Figure 1 is a diagram of a decision "tree." The black squares in the figure are eferred to as nodes. At each node, SEARCH determines the most significant independent ariable. If the selected independent variable is significant at the user-supplied



Fiure 1. Decision "tree."

```
      PROBABILITY OF MORTALITY (WWPV),95% SIGNIFICANCE LEVEL
                                           TIP VIGOR
                                               POOR
                            CROWN CLASS        FAIR
                                SUP            ........
                                INT            .000044.
                                CODOM          .000061.
                                ........       ........
             CROWN VIGOR        .000075.       GOOD
                  POOR          .000076.       ........
                  ........      ........       .000031.
                  .000084.                     .000015.
                  .000076.                     ........
                  ........

                                DOM
                                ........
                                .000009.
                                .000000.
                                ........

STATUS            FAIR
    ALIVE         ........
    DEAD          .000159.
    ........      .000055.
    .000761.      ........
    .000195.
    ........
                            DBH AS PERCE
                                0-15
                                ........
                                .000046.
                                .000018.
                                ........
                  GOOD
                  EXCELL                   CROWN RATIO
                  ........                     0-2
                  .000518.      15-30          2-4
                  .000064.      30-45          ........
                  ........      45-60          .000115.
                                60-70          .000020.
                                70-80          ........
                                80-90
                                90-100         4-5       DIE BACK
                                ........       5-6           EXTEN
                                .000472.       6-7           ........
                                .000046.       7-8           .000003.
                                ........       8-9           .000003.
                                               9-10          ........
                                               ........      MOD
                                               .000357.      ABSENT
                                               .000026.      ........
                                               ........      .000354.
                                                             .000023.
                                                             ........
```

Figure 2. Output "tree" produced by GRAPH showing results of screening done in SEARCH.

significance level, it is included in the decision "tree" as the next best predictor of the two possible outcomes of the dependent variable. An example of the decision "tree" produced by GRAPH is given in figure 2.

SEARCH and GRAPH were originally written by Malcolm Gleser in PL/1 48 character set[1] and have been compiled under version 5 of the PL/1 compiler. The present authors modified the procedures and prepared this documentation of the modified procedures.

---

[1]IBM System/360 operating system: PL/1 (F), Language Reference Manual Order No. GC28-8201.

USES AND PROPERTIES OF SCREEN

This method of analysis has a large number of uses, each of which can be classified either as a screening technique, preliminary to model building, or as a modeling technique. In either application, the user must remember that the results of a screen of relationships between dependent and independent variables only provide a portion of the information needed for the development of a model. Known biological relationships and constraints must also be included in the modeling process.

Many screening algorithms assume a specific functional relationship between the dependent and the independent variables. Grosenbaugh (1967) and Furnival (1971) described such screening algorithms. Stepwise-regression algorithms are additional examples of such algorithms, in which screening is accomplished by computing some goodness-of-fit statistic for each set of independent variables to be considered. SEARCH, however, assumes no functional relationship.

When SEARCH is used as a data screening procedure, results provide the user with an optimal set of independent variables for describing the behavior of the dependent variable. If a model is to be constructed from this set of independent variables, the user must determine the nature of the functional relationship between the dependent and independent variables and the validity of any variable transformations that might be expected to improve the goodness-of-fit of the relationship.

Similarly, the user must work with independent variables that are either discrete, with no more than eight classes, or that can be transformed into discrete classes. When continuous variables are transformed, discrete classes need not be of equal width. For example, the variable age might be grouped: age unknown, 0-30 years, 31-40 years, 41-50 years, 51-75 years, and 75 years and over. Discrete classes for continuous independent variables should be defined with considerable care. If classes are too broad, differences in the relationship between dependent and independent variables may be masked. The algorithm will combine classes in which the relationship is similar. Thus, it is usually preferable to define too many discrete classes than to define a few broad classes.

The algorithm described in the SEARCH procedure is independent of most assumptions oncerning the numerical structure of data. No distributional assumptions are required or the independent variables other than that they be discrete or readily transformed o discrete variables Screening is not restricted by the need to make any assumptions bout the nature of the functional relationship between the dependent and independent ariables. Also, screening is unaffected by any transformations of the independent ariables as long as a one-to-one relationship is maintained between transformed and ntransformed variables.

SEARCH does provide guidance as to significant interactions between independent variables, as is shown by the example of program output in figure 2. For white pine with POOR crown vigor, crown class is the next most significant predictor of mortality. For white pine with GOOD or EXCELLENT crown vigor, d.b.h. as a percentage is more significant than crown class. This result could be explained by a significant interaction between crown class and crown vigor and between d.b.h. as a percent and crown vigor.

We have used SEARCH extensively as a screening technique prior to model building. Currently (1974), we are conducting a study to develop models that will predict tree mortality as a function of anatomical characteristics of the tree. The output "tree" in figure 2 is the output from the GRAPH procedure that resulted from analyzing a population of western white pine that had been measured at 5-year intervals for 20 years (1941-1961). The population is made up of 956 tree records, each of which consists of observations on 15 variables. This population will be used as an example throughout this report to show the data input required to operate SEARCH and GRAPH and to help explain the output of these two procedures. The set of variables selected by SEARCH will be used to develop a functional model that will predict the probability of a white pine becoming a mortality tree in any given 5 years. Similar efforts are underway to develop models that will predict annual mortality rates for all northern Idaho species.

It is not always necessary to develop a functional model from the output of GRAPH. Frequently, the user may be seeking only to identify those variables of importance for future study. In such situations, the "tree" printed by GRAPH provides all information required as to which independent variables are significant predictors of the dependent variable.

This use of SEARCH is more nearly equated with the use for which the procedure was developed (Gleser and Collen 1972). We have used SEARCH to analyze a data set collected to investigate levels and trends of natural inactivation of blister rust cankers on western white pine. The "tree" printed by GRAPH indicates which variables provide most information about the active or inactive status of a canker.

We feel that SEARCH is a valuable data-screening tool in any situation for which the dependent variable is dichotomous. SEARCH could also be used to study:

1. The presence or absence of a resistance mechanism to mountain pine beetle infestation in lodgepole pine;

2. regeneration in order to predict presence or absence of stocked quadrats;

3. the presence or absence of cone serotiny in lodgepole pine; and

4. the presence or absence of cull volume in apparently sound trees.

In each of these examples, SEARCH would be used to select those variables that best predict the relative frequency of occurrence of the two states of the dependent variable.

GUIDES FOR THE USE OF SEARCH AND GRAPH

Three distinct steps are included in an analysis of data by the SCREEN program. rst, the data to be analyzed must be transformed and written in a specific format in le INPUT. The actual screening is then performed by executing the PL/1 procedure, ARCH. Finally, the results of the data screening are printed in a decision "tree" rmat by executing the PL/1 procedure, GRAPH.

The input for SEARCH is on two files:

le INPUT:

File INPUT must be created in a separate job and written on a data set. This file ntains observation records, including both independent and dependent variables.

When the INPUT data set is allocated, LRECL (logical record length) should be set ual to the number of variables; for example, if each record consists of 14 variables, ECL should be exactly 14 bytes. Each byte on a record represents one variable, that , byte 1 is for variable 1, byte 2 is for variable 2, and so on. Each independent riable can take on a character value of from 0 to 7, and each dependent variable can ke on a character value of 0 or 1. If an independent variable has only two possible tcomes, these outcomes must be represented by 0 or 1. Similarly, if there are only ree outcomes, the outcomes are 0, 1, or 2. All records must be complete since missing ta would be interpreted as a zero code. A possible solution to the missing data oblem is to include an "unknown" class for those variables affected.

Since the tree records for the example population consisted of 15 variables, the cord length for INPUT was 15. These variables were as follows:

riable	No. of outcomes	Possible outcomes
1 DBH	7	(0) 2-10; (1) 10-15; (2) 15-20; (3) 20-25; (4) 25-30; (5) 30-35; (6) 35-40
2 BOLE COND	6	(0) OK; (1) UNSUCCESSFUL BEETLE ATTACK; (2) SUCCESSFUL BEETLE ATTACK; (3) BROKEN TOP; (4) DEAD FORK; (5) ROT
3 CROWN CLASS	4	(0) SUPPRESSED: (1) INTERMEDIATE; (2) CODOMINANT; (3) DOMINANT
4 TIP CHAR	3	(0) BROKEN: (1) SPRAYED OUT; (2) POINTED
5 TIP VIGOR	3	(0) POOR; (1) FAIR; (2) GOOD
6 CROWN WIDTH	3	(0) NARROW; (1) MEDIUM; (2) WIDE

Variable	No. of outcomes	Possible outcomes
7. CROWN RATIO	8	(0) 0-2; (1) 2-4; (2) 4-5; (3) 5-6; (4) 6-7; (5) 7-8; (6) 8-9; (7) 9-10
8. CROWN FORM	5	(0) RAGGED; (1) RAGGED 1-SIDED; (2) 1-SIDED; (3) UNIFORM-RAGGED; (4) UNIFORM
9. CROWN COLOR	3	(0) YELLOW; (1) LIGHT GREEN; (2) GREEN
10. DIE BACK	3	(0) EXTENSIVE; (1) MODERATE; (2) ABSENT
11. CROWN DENSITY	3	(0) POOR; (1) FAIR; (2) GOOD
12. CROWN VIGOR	4	(0) POOR; (1) FAIR; (2) GOOD; (3) EXCELLENT
13. STATUS	2	(0) ALIVE; (1) DEAD
14. DBH AS PERCENT	8	(0) 0-15; (1) 15-30; (2) 30-45; (3) 45-60; (4) 60-70; (5) 70-80; (6) 80-90; (7) 90-100
15. SITE INDEX	8	(0) 0-40; (1) 40-50; (2) 50-60; (3) 60-70; (4) 70-80; (5) 80-90; (6) 90-100; (7) 100+

Suppose columns 1-15 of the first record contained the following values:

2 0 1 2 1 0 4 0 1 0 0 1 1 1 3

Then, the first observation represents a tree with the following characteristics:

(A) Diameter 15-20 inches (2);

(B) OK bole condition (0);

(C) Intermediate crown class (1);

(D) Pointed tip (2);

(E) Fair tip vigor (1);

(F) Narrow crown width (0);

(G) Live crown for 60-70 percent of total height (4):

(H) Ragged crown form (0);

(I) Crown color light green (1):

(J) Extensive dieback (0);

(K) Poor crown density (0);

(L) Fair crown vigor (1);

(M) Dead (1);

(N) Percentage position in the d.b.h. distribution of 15-30 percent (1);

(O) Site index 60-70 (3).

le SYSIN (card input):

Card Type 1

lumns	Variable	Type	PL/1 format	Description
-6	NVAR	Integer	F(6)	Number of variables
-12	NLR	Integer	F(6)	Number of observations
-18	LRECL	Integer	F(6)	Logical record length of file INPUT
4	INPT	Integer	F(6)	= 1 if file INPUT can be held in memory all at once = 0 or blank if file INPUT is to be read in one record at a time

Discussion of Card Type 1: If file INPUT is small enough to be held in memory l at once, then on many computers it is more efficient to do so. In this case, lumn 24 of card 1 should contain a 1.

However, if the product of NVAR and NLR is greater than 32,676, this method of ading file INPUT results in subscripts being created in SEARCH that exceed the magni- de of subscripts permitted in PL/1. Thus, the file must be read and processed one servation at a time. In this case, column 24 should contain a zero or blank.

A way to reduce input costs when each record is read one at a time is to create le INPUT with a large block size, which reduces the input-output count. However, is method also requires a substantial increase in the amount of memory needed to exe- te the program. We have found that the computer price structure at Washington State iversity results in lower costs when the input-output count is reduced at the expense increased memory sizes. A second means of handling large INPUT files is to screen subset of the observations. When a subset is screened, care must be taken to assure at the subset is a valid sample of the population of interest.

Card Type 2: The Variable Name Cards

lumns	Variable	Type	PL/1 format	Description
1	NCTG(I)	Integer	F(1)	The number of possible out- comes (2-8) for the Ith variable
-13	VN(I)	Character	A(12)	The name of the Ith variable
-24	VNS(I,J)	Character	A(8)	Name of the Jth outcome
32				(J=1,...,8) for the Ith variable

Discussion of Card Type 2: For each variable there must be one card containing the above information. The variable name cards are ordered to correspond to the order of each variable on the input record. There must be a variable name card for each variable on the input record.

Card Type 3: The Variable Inclusion Card(s)

Columns	Variable	Type	PL/1 format	Description
1	INDEX(1)	Integer	A(1)	= blank if variable 1 is to be used as a predictor = 1 if variable 1 is to be omitted or is a dependent variable
2	INDEX(2)	Integer	A(1)	= blank if variable 2 is to be used as a predictor = 1 if variable 2 is to be omitted or is a dependent variable
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
NVAR	INDEX(NVAR)	Integer	A(1)	= blank if variable NVAR is to be used as a predictor = 1 if variable NVAR is to be omitted or is a dependent variable

Discussion of Card Type 3: The variable inclusion control card(s) is used to specify which variables in the input record are to be used as independent variables. Each column of the variable control card corresponds to a position on each of the data input records. If the variable in position 30 of the input record is not to be used as an independent variable, a 1 is entered in column 30 of the variable control card. If there are more than 80 variables per record, several variable inclusion cards are used. Thus, if a record contains 220 variables and if variable number 220 is not to be used as an independent variable, a 1 is placed in column 60 of the third variable inclusion card. Each blank column of the variable control card will cause that variable to be included in the analysis as an independent variable. Any column corresponding to a dependent variable must contain a 1.

Card Type 4: The Control of Analysis Card

Columns	Variable	Type	PL/1 format	Description
1-6	NTOTAL	Integer	F(6)	Number of observations to be used in this analysis, $\leq$NLR
7-12	DVAR#	Integer	F(6)	Column number of the dependent variable on the logical input record

Columns	Variable	Type	PL/1 format	Description
3-18	LEVEL#	Integer	F(6)	Depth to which SEARCH will go, or the maximum number of nodes along each branch. LEVEL# usually is ≤ 8, but it can be as large as 12
9-24	FLEV#	Integer	F(6)	Level of the first node. This is blank or zero in the normal circumstance. If it is ≥ 1, then the next card will be card type 5 with information as to what the first nodes will be

Discussion of Card Type 4: NTOTAL can be used to limit the analysis to a subset of the total population. Any value of NTOTAL less than NLR will limit the analysis to the first NTOTAL observations in the population.

LEVEL# is usually specified to be ≤ 8. Rarely in our uses of SEARCH have as many as 8 variables been significant predictors of the outcome of the dependent variable. In addition, an 8-node "tree" output produced by GRAPH just fits across the width of a page of computer paper.

Card Type 5: The Node Specification Card

Columns	Variable	Type	PL/1 format	Description
1-3	TB(1,1)	Integer	F(3)	Variable number for first forced node
4	TB(1,3)	Integer	F(1)	Lowest desired independent outcome number for first forced node
5	TB(1,4)	Integer	F(1)	Highest desired independent outcome number for first forced node
6-8	TB(2,1)	Integer	F(3)	Variable number for second forced node
9	TB(2,3)	Integer	F(1)	Lowest desired independent outcome number for second forced node
10	TB(2,4)	Integer	F(1)	Highest desired independent outcome number for second forced node
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
5*I-4)- 5*I-2)	TB(I,1)	Integer	F(3)	Variable number for Ith forced node, where I = FLEV#
5*I-1)	TB(I,3)	Integer	F(1)	Lowest desired independent outcome number for Ith forced node
*I)	TB(I,4)	Integer	F(1)	Highest desired independent outcome number for Ith forced node

Discussion of Card Type 5: This card is included only if the value of FLEV# (forced level number) on card type 4 is ≥1. This card is used to limit the data considered by the SEARCH algorithm to a subset of the population. For the Ith forced variable, three values, TB(I,1), TB(I,3), and TB(I,4), must be read from the node specification card.

In the example discussed previously, we might be concerned with predicting mortality only for those trees with d.b.h. >20 inches and with wide crowns. Thus, FLEV# would be set equal to 2. D.b.h. is variable 1. Outcomes 3, 4, 5, and 6 represent trees >20 inches. Thus, the first 5 columns of the node specification card would contain the values:

00136

Crown width is variable 6. Wide crowns are coded 2. Thus, columns 6 through 10 of the node specification card would contain the values:

00622

This card will cause SEARCH to include in the screening only those observations with d.b.h. >20 inches, coded 3, 4, 5, or 6, and wide crowns coded 2.

Card Type 6: The Significance Level Card

Columns	Variable	Type	PL/1 format	Description
1-5	X05(1)	Real	F(5,1)	Chi-square value for 1 degree of freedom at the user supplied significance level
6-10	X05(2)	Real	F(5,1)	Chi-square value for 2 degrees of freedom at the user supplied significance level
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
31-35	X05(7)	Real	F(5,1)	Chi-square value for 7 degrees of freedom at the user supplied signifiance level
36-40	SIGLEV	Real	F(5)	% of the user supplied significance level times 100; for example, a 95% significance level would be expressed as 9500

Discussion of Card Type 6: At each node, SEARCH selects the most significant independent variable only if that variable is significant at the user-supplied significance level. If no independent variable is significant, that branch of the "tree" diagram is terminated. Thus, the extent of the diagram can be controlled by manipulating the significance level.

In certain cases, it is desirable to specify a low significance level such as 50 or 75 percent. If no strong relationship exists between dependent and independent variables, a low significance level will result in independent variables being ranked according to the relative importance. Similarly, a low value of SIGLEV may be necessary if the population being screened is small.

Cards Necessary for Multiple Runs:

SEARCH is designed to permit the use of the same INPUT file for multiple runs of the program. This feature of SEARCH is of value to the user who wishes to screen a data set at a number of significance levels or who wishes to investigate the results of alternative restrictions of the set of independent variables. When multiple runs are desired, the following control cards must be included for each run after the initial run:

1. Variable inclusion card(s);

2. the control of analysis card; and

3. the significance level card.

Example of Input Cards for File SYSIN:

Figure 3 provides an example of input cards that were required to run the example discussed previously. Card type 5 is omitted because we did not force any nodes in this example.

Card type 1 tells us that each of the 956 data records in the population is made up of 15 variables; so the record length of file INPUT is set at 15. File INPUT is to be read one record at a time.

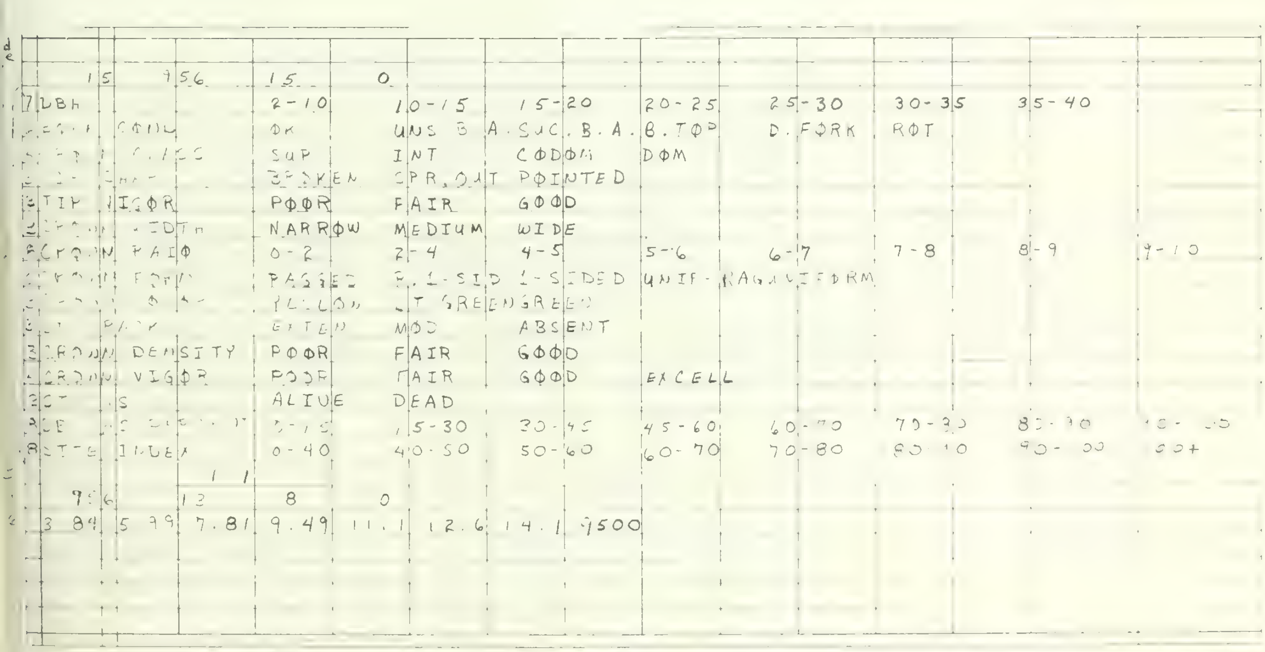


Figure 3. Example of input cards needed to operate SEARCH.

The set of type 2 cards defines the 15 variables. The number and the definition of the classes of each variable are also specified on these cards.

Card type 3 excludes variables 13 (status) and 15 (site index) from the set of independent variables.

Card type 4 states that 956 observations will be used in this analysis. Variable 13 will be the dependent variable for this run. SEARCH will run for a maximum of 8 nodes. No nodes will be forced in this run.

Since no nodes are to be forced, card type 5 is unnecessary. Card type 6 specifies that the significance level for this run will be 95 percent. The first seven numbers on this card are the significant chi-square values for 1 through 7 degrees of freedom.

OUTPUT From SEARCH

Output consists primarily of punched cards to be used in a second procedure, GRAPH. However, some printed output is provided.

The first page of printed output contains two blocks of printout. The first block consists of the variable name cards that correspond to those variables to be used as independent variables. The second block contains the variable name cards that correspond to those variables not to be used as independent variables.

Values of the following variables are printed on the second page:

Variable	Description
NTOTAL	Same as NTOTAL on control of analysis card.
NVAR	Same as NVAR on Card Type 1
DVAR#	Same as DVAR# on control of analysis card
LRECL	Same as LRECL on Card Type 1
INPT	Same as INPT on Card Type 1
LEVEL#	Same as LEVEL# on control of analysis card
FLEV#	Same as FLEV# on control of analysis card
MNUM	Minimum number of observations required in each category
X05(1)-X05(7), SIGLEV	Same as on significance level card
TAB(I,J)	A series of 2x N_K contingency tables formed by cross classifying the population by the dependent and by each independent variable. J can be 0 or 1, and I runs from 1 to $\sum_{K=1}^{INDPT} N_K$, where

Variable	Description
	INDPT = number of included independent variables used in the run and N_K = number of possible outcomes for the Kth included independent variable.

The dependent variable in the example discussed earlier is STATUS and the first independent variable is DBH with 7 possible outcomes. Thus TAB(I,J) is defined as:

TAB(1,0) = number of observations with "0" STATUS in in the "0" DBH category

TAB(1,1) = number of observations with "1" STATUS in the "0" DBH category

TAB(2,0) = number of observations with "0" STATUS in the "1" DBH category

TAB(2,1) = number of observations with "1" STATUS in the "1" DBH category

.
.
.

TAB(7,0) = number of observations with "0" STATUS in the "6" DBH category

TAB(7,1) = number of observations with "1" STATUS in the "6" DBH category

The next independent variable is BOLE COND with 6 possible outcomes. Thus:

TAB(8,0) = number of observations with "0" STATUS in the "0" BOLE COND category

TAB(8,1) = number of observations with "1" STATUS in the "0" BOLE COND category

.
.
.

TAB(13,1) = number of observations with "1" STATUS in the "5" BOLE COND category

The final independent variable is SITE INDEX with 8 possible outcomes. Thus, the final element of TAB(I,J) is:

TAB(68,1) = number of observations with "1" STATUS in the "7" SITE INDEX category

Variable	Description
DØUT(0)	= total number of observations with a dependent variable of 0.
DØUT(1)	= total number of observations with a dependent variable of 1.

NOTE: DØUT(0) + DØUT(1) should equal NTOTAL

The punched card output produced by SEARCH is also printed as the next lines of output. The final line of output lists the value of EXIT#. The program terminates by encountering an end of file on file SYSIN or on file INPUT. EXIT# identifies the particular GET statement where SEARCH terminates.

The following chart lists the meaning of the different EXIT#'s:

EXIT #	Procedure card sequence number where end of file occurred	Condition of termination
1	SRCH 190	End of file encountered as program read Card Type 1
2	SRCH 550	Normal termination
3	SRCH 580	NVAR>80. End of file encountered as program read continuation of variable inclusion card
4	SRCH 450	End of file encountered as program read variable name card
5	SRCH 990	End of file encountered as program read control of analysis card
6	SRCH1040	End of file encountered as program read node specification card
8	SRCH1530	End of file encountered as program read significance level card
11	SRCH3060	End of file encountered as program read file INPUT one observation at a time
12	SRCH3000	End of file encountered as program read file INPUT all at one time

Occurrence of EXIT#'s 1,3,4,5,6, or 8 indicates that the input cards to file SYSIN have been prepared incorrectly or that some have been omitted. Occurrence of EXIT#'s 11 or 12 indicates that there are fewer observations in file INPUT than were recorded on card type 1.

SEARCH also creates a temporary file PASS. This file contains the same information as the punched card output records created by SEARCH, which permits the user to run SEARCH and GRAPH as two job steps in a single batch job. The job-control cards needed to do this are listed in the SAMPLE JCL (job-control language) section following the discussion of GRAPH.

USER INFORMATION FOR GRAPH

GRAPH is the procedure that prints the "tree" diagram(s) generated by the SEARCH procedure.

SYSIN and PASS are the two input files for GRAPH. SYSIN is card input prepared by the user. PASS either can be the punched cards produced by SEARCH or, if SEARCH and GRAPH are run as two job steps in the same batch job, a temporary data set passed from SEARCH. Details of the job-control language needed to use these files are presented in the SAMPLE JCL section.

File SYSIN must contain the following cards:

Card Type 1

Columns	Variable	Type	PL/1 format	Description
1-6	NVAR	Integer	F(6)	Number of variables

Card Type 2

These are the same as the variable name cards used in SEARCH, where

N = number of categories

VN(I) = name of the Ith variable

VNS(I,J) = name of the Jth category for the Ith variable

Card Type 3

olumns	Variable	Type	PL/1 format	Description
1-3	NNN	Integer	F(3)	Position number of the dependent variable, same as DVAR# in SEARCH
4-80	TITLE	Character	A(77)	Title to be used as page header for the "tree" diagram

Card Type 4: Control of Analysis Card

Columns	Variable	Type	PL/1 format	Description
19-24	FLEV#	Integer	F(6)	Number of forced nodes in this run

The value for FLEV# on this card must be the same as the value for FLEV# used in SEARCH.

Cards Necessary for Multiple Runs:

Multiple runs of GRAPH are also possible. For each "tree" diagram that is to be printed after the initial diagram, the following control cards must be included:

In file SYSIN,

1. Title card; and
2. control of analysis card.

In file PASS,

1. Punched card output or equivalent records in temporary data set.

Example of Input Cards for File Sysin:

Figure 4 provides an example of the input cards needed to print the "tree" diagram produced by the SEARCH run described earlier.

Printed "Tree" Diagram Output From Graph

Printed for each problem run in SEARCH is a "tree" diagram, consisting of the dependent variable as a root and combinations of significant predictors as branches. The "tree" should be read from left to right. Each branch represents the best set of predictors for a specific combination of independent variable outcomes.

The sample "tree" printout in figure 2 reports the optimal set of predictors for western white pine mortality. This "tree" was produced by the SEARCH run described in figure 3 and by the GRAPH run described in figure 4. Crown vigor categories separate white pine into three different mortality ratio classes. White pine with either good or excellent crown vigor apparently have similar mortality ratios. Within the poor crown-vigor category, the next best predictor is crown class. White pines with codominant, intermediate, or suppressed crown class have similar mortality ratios, which is significantly different from the mortality ratio associated with white pine with dominant crown class. By contrast, for those white pines with good or excellent crown vigor, d.b.h. as a percent is the next best predictor, although only the lowest class has a mortality ratio different from the other classes. For white pine with fair crown vigor, none of the potential independent variables provides any further significant discriminating power.

For white pine with poor crown vigor and codominant, intermediate, or suppressed crown class, tip vigor is the next best predictor. Trees with good tip vigor have a

Card Type									
1	15								
2	7 DBH	2-10	10-15	15-20	20-25	25-30	30-35	35-40	
	6 BØLE CØND	ØK	UNS. B.A.	SUC. B.A.	B. TØP	D. FØRK	RØT		
	4 CRØWN CLASS	SUP	INT	CØDØM	DØM				
	3 TIP CHAR	BRØKEN	SPR. ØUT	PØINTED					
	3 TIP VIGØR	PØØR	FAIR	GØØD					
	3 CRØWN WIDTH	NARRØW	MEDIUM	WIDE					
	8 CRØWN RATIØ	0-2	2-4	4-5	5-6	6-7	7-8	8-9	9-10
	5 CRØWN FØRM	RAGGED	R. 1-SID	1-SIDED	UNIF-RAG	UNIFØRM			
	3 CRØWN CØLØR	YELLØW	LT GREEN	GREEN					
	3 DIE BACK	EXTEN	MØD	ABSENT					
	3 CRØWN DENSITY	PØØR	FAIR	GØØD					
	4 CRØWN VIGØR	PØØR	FAIR	GØØD	EXCELL				
	2 STATUS	ALIVE	DEAD						
	8 DBH AS PERCENT	0-15	15-30	30-45	45-60	60-70	70-80	80-90	90-100
	8 SITE INDEX	0-40	40-50	50-60	60-70	70-80	80-90	90-100	100+
3	13 PRØBABILITY ØF MØRTALITY (WWPU), 95% SIGNIFICANCE LEVEL								
4			0						

Figure 4. Example of input cards needed to operate GRAPH.

different mortality ratio than do trees with poor or fair tip vigor. For those trees with poor crown vigor and dominant crown class, there are no further significant predictors. For those trees with good or excellent crown vigor and d.b.h. as a percent greater than 15 percent, crown ratio and dieback also are significant predictors.

The numbers in the boxes have a specific meaning. The box under GOOD tip vigor contains a 31 and a 15. The 31 indicates that there were 31 live white pines that had characteristics of POOR crown vigor, that were in the SUP-INT-CODOM crown class, and that had GOOD tip vigor. The 15 indicates that there were 15 dead white pines with the same set of characteristics.

At the completion of all "tree" printouts, EXIT# is listed to indicate the point of termination in GRAPH.

The following chart lists the meaning of the different EXIT#'s:

EXIT#	Procedure card sequence number where end of file occurred	Condition of termination
1	GRPH 60	End of file encountered as program read Card Type 1
2	GRPH 400	Normal termination

EXIT#	Procedure card sequence number where end of file occurred	Condition of termination
3	GRPH 590	End of file encountered as program read file PASS
4	GRPH 540	End of file encountered as program read control of analysis card
5	GRPH 310	End of file encountered as program read the variable name cards

The occurrence of EXIT#'s 1,4, or 5 indicates that file SYSIN has been prepared incorrectly or that some needed cards have been omitted. Occurrence of EXIT# 3 indicates that file PASS is incomplete.

The following examples of JCL are provided for the guidance of those who will run the program on a standard IBM 360 Operating System. To those who use computers with other operating systems, examples show files and parameters that must be defined for the operation of SEARCH and GRAPH.

SAMPLE JCL FOR THE IBM 360/67 ØS

To run SEARCH alone from the deck:

```
JØB CARD
// EXEC PL1LFCLG,PARM.PL1L='C48',REGIØN.PL1L=98K,
// REGIØN.GØ=130K
//PL1L.SYSIN DD *

     SEARCH deck

//GØ.SYSPRINT DD SYSØUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
//GØ.PUNCH DD SYSØUT=B
//GØ.PASS DD DSN=&&TEMP,DISP=(NEW,PASS),SPACE=(TRK,(4,1)),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=7280,DSØRG=PS),UNIT=SYSSCR
//GØ.INPUT DD DSN=data set name of observation data set created in previous job,
     DISP=SHR
//GØ.SYSIN DD *

     Data input cards
```

To run GRAPH alone from the deck:

```
JØB CARD
// EXEC PL1LFCLG,PARM.PL1L='C48',REGIØN.PL1L=98K,
// REGIØN.GØ=138K
//PL1L.SYSIN DD *
```

GRAPH deck

```
/GØ.SYSPRINT DD SYSØUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
/GØ.PASS DD *
    punched cards from SEARCH
/GØ.SYSIN DD *
    SYSIN cards for GRAPH
```

o run SEARCH and GRAPH together from decks:

```
ØB CARD
/ EXEC PL1LFCLG,PARM.PL1L='C48',REGIØN.PL1L=98K,
/ REGIØN.GØ=130K
/PL1L.SYSIN DD *

    SEARCH deck

/GØ.SYSPRINT DD SYSØUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
/GØ.PUNCH DD SYSØUT=B
/GØ.PASS DD DSN=&&TEMP,DISP=(NEW,PASS),SPACE=(TRK,(4,1)),
/ DCB=(RECFM=FB,LRECL=80,BLKSIZE=7280,DSØRG=PS),UNIT=SYSSCR
/GØ.INPUT DD DSN=data set name of observation data set created in previous job,
    DISP=SHR
/GØ.SYSIN DD *

    Data input cards

/ EXEC PL1LFCLG,PARM.PL1L='C48',REGIØN.PL1L=98K,
/ REGIØN.GØ=138K
/PL1L.SYSIN DD *

    GRAPH deck

/LKED.SYSLMØD DD DSN=&&GØSET(GØ),DISP=(NEW,PASS),
/ DCB=BLKSIZE=1024,UNIT=SYSSCR,SPACE=(CYL,(1,1,1))
/GØ.SYSPRINT DD SYSØUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
/GØ.PASS DD DSN=&&TEMP,DISP=(ØLD,PASS)
/GØ.SYSIN DD *

    SYSIN cards for GRAPH
```

SEARCH requires 98K bytes of memory to compile. The amount of memory required to (ecute SEARCH varies from about 100K bytes to 160K bytes depending on the size of the)pulation to be screened and on the number of variables in each observation. GRAPH (quires 98K bytes of memory to compile and 138K bytes of memory to execute.

GRAPH will usually execute in less than 1 minute central processing unit (CPU) time. ARCH will usually execute in less than 2 minutes CPU time. However, an increase in pulation size, an increase in the number of variables per observation, or a decrease significance level will result in an increase in the execution time required by ARCH.

Requests for the program should be directed to:
Intermountain Forest and Range Experiment Station
Forestry Sciences Laboratory
Attention: David A. Hamilton, Jr.
1221 South Main Street
Moscow, Idaho 83843

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☆U.S. GOVERNMENT PRINTING OFFICE: 1975 — 677-328 / 3 REGION NO. 8

HAMILTON, DAVID A., JR., and DONNA L. R. WENDT
1975. SCREEN: a computer program to identify predictors of dichotomous dependent variables. USDA For. Serv. Gen. Tech. Rep. INT-22, 20 p. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

The algorithm reported here is a modeling tool that screens potential relationships between a set of independent variables and a dichotomous dependent variable. Uses of the algorithm and its properties are discussed. A user's guide explains the preparation of input cards for the two PL/1 procedures and explains the program output.

OXFORD: U681.3;--015.5.
KEYWORDS: computer programs, statistical methods, data screening algorithm, nonlinear regression, dichotomous dependent variable, modeling.

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A Computer Algorithm for Sorting Field Data on Fuel Depths

Frank A. Albini

USDA Forest Service
General Technical Report INT-23, 1975
INTERMOUNTAIN FOREST AND RANGE
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Ogden, Utah 84401

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USDA Forest Service
General Technical Report INT-23
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A COMPUTER ALGORITHM FOR SORTING FIELD DATA ON FUEL DEPTHS

Frank A. Albini

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ABSTRACT

Describes an algorithm for separating fuel depth data into distinctive groups of measurements. The algorithm is justified heuristically, through its mathematical similarity to the "tuner" of a radio receiver. Test data generated artificially were used to maximize the sensitivity of the algorithm. The algorithm has been applied successfully to field data gathered by standard fuel inventory procedures, but output should be verified by someone familiar with the sampled area. A rough flow chart and a FORTRAN listing are included. Copies of the computer program are available from the author.

INTRODUCTION

Several published methods for inventorying wildland fuels (Van Wagner 1968; Brown 971; USDA Forest Service 1974) and another in preparation[1] entail the sampling of fuel epths. The vertical height to the uppermost fuel component is recorded at each of any sample points. When the net of sample points is sufficiently dense, this procedure hould approximate the "sheet depth" estimation procedure (Brown 1971); but in some ases the captured information would prohibit the interpretation of it as such without pecial effort.

To illustrate, consider the following conceptual arrangement of fuel pieces: owels, 1 cm in diameter, extending vertically 1 m above the terrain surface, are laced 20 cm apart in a uniform square grid. Using the "sheet depth" estimation procedure, a 1-m average fuel depth would be deduced. If a sampling technique were used, ith the sample locations chosen at random, the resulting *average* depth would depend pon the details of the sampling procedure.

One common method of depth sampling is the random selection of points at which amples are to be made. Then a 5-cm radius circle is lowered vertically, with the lane of the circle held horizontally, until the circular area intercepts a fuel element. n our example, the intercept would occur at a height of 1 m if the centerline of a owel fell within 5.5 cm of the center of the sampling circle. In other words, areas $\pi(5.5)^2 = 95$ cm^2 are selected at random from the general area. If a dowel centerne lies within that area, a depth of 1 m is recorded; if not, a depth of zero is ecorded. Since the density of dowel centerlines in the area is one per 400 cm^2, the obability of intercepting a centerline on any given measurement is 95/400, or 0.238. , for a large enough set of sample points, the recorded fuel depths would be 23.8 rcent at 1 m and 76.2 percent at zero, and an average depth of 23.8 cm would be mputed.

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[1]Frandsen, William H. A firespread model for spatially nonuniform forest floor el arrays. Problem analysis, USDA For. Serv., Intermt. For. and Range Exp. Stn., rth. For. Fire Lab., Missoula, Mont. (in preparation).

The reason for inventorying wildland fuels is, oftentimes, to predict fire behav Rothermel's spread rate model (1972) is quite sensitive to the depth of the fuel bed, so it is important to have an accurate estimate of this quantity for each fuel comple to be assessed.

Of course, in the example just cited, one could deduce the appropriate average depth of 1 m simply by discarding all the zero-depth measurements. But, suppose that a sparsely distributed shrub of 30-cm height were growing in an area of general timbe litter with a 3-cm mean depth. The problem of data interpretation again would arise much the same form.

There would be no problem if the fuel type were noted on data recording forms, c if there were adequate onsite photography. When such clues are not available, some scheme is needed for objectively reducing raw data.

Two types of problems must be considered: One problem, much like that outlined above, is when the depth measurements within a reasonably homogeneous region of fuel cover do not lend themselves to simple averaging to produce a representative fuel dep estimate. The second problem occurs when depth measurements of two or more distinct fuel communities are intermingled in the data in such a way that they cannot be separ

In both cases the problem can be posed in terms of finding distinctive groups of depth measurements in the data set, which presumably represent measurements of distin tive fuel complexes. In the first case, it is a matter of rejecting spurious data-- those measurements that result in unreasonably high or low depth values and would poison the average if included, such as a few 2-m measurements in a litter-fuel regic with a true average of, say, 5 cm. In the second case, one would seek to characteriz the distinctive fuel complexes for separate analyses.

This paper describes an algorithm developed for processing fuel depth data, such as that just described, with the intent of separating distinctive groups of measurements. The approach taken is entirely heuristic, but the method was tested against artificial data and the process was adjusted to produce the best results. The algori has been applied to data taken on wildland fuels. These data illustrate the fact tha the procedure cannot be applied blindly, but that scrutiny of algorithm output by pec familiar with the locale in question is required.

METHOD

The mathematical problem posed can be envisioned in terms of placing boundary oints on the horizontal axis of a histogram of the depth-measurement data. If such elimiting depth values could be placed accurately, they would mark off the sets of easurements which should be considered together in forming averages representative f the distinctive fuel complexes.

If a histogram were constructed by superimposing measurements from three signifiantly different fuel complexes (fig. 1), an analyst would have no difficulty in iscerning the three distinctive groupings of data. In figure 1, the shallow population exhibits a normal histogram that is quite distinctive. The more erratic distriation between 30 and 47 cm appears abnormal, but is nonetheless clearly a separate opulation. The four vertical bars at the right of figure 1 display another characterstic frequently encountered in such data sets--depths appear to have been recorded to ne nearest 5 cm. With this in mind, our analyst would presumably consider the 60-75 cm ita to be a distinctive group.

To program a computing machine to make the same kinds of decisions as would presumly be made by an analyst is difficult in an absolute sense because of the subtleties volved in human pattern perception. But the limited problem at hand is susceptible a simplified approach, illustrated in the following discussion.

If the histogram of figure 1 were reconstructed, grouping those measurements that ll within some tolerance or accuracy band of each other, a tighter clumping of the eater depth groups would occur. This procedure would in itself make the patterns re distinctive.

In other words, if we consider that the bin labeled "2 cm" really captures all asurements between 1.5 and 2.5 cm, we can see that an equally reasonable partitioning the data would be into bins that have a variable range of depth spreads. The partiions could be established by specifying a fraction of the nominal depth label for ch bin within which a measurement must fall to be included in that bin.

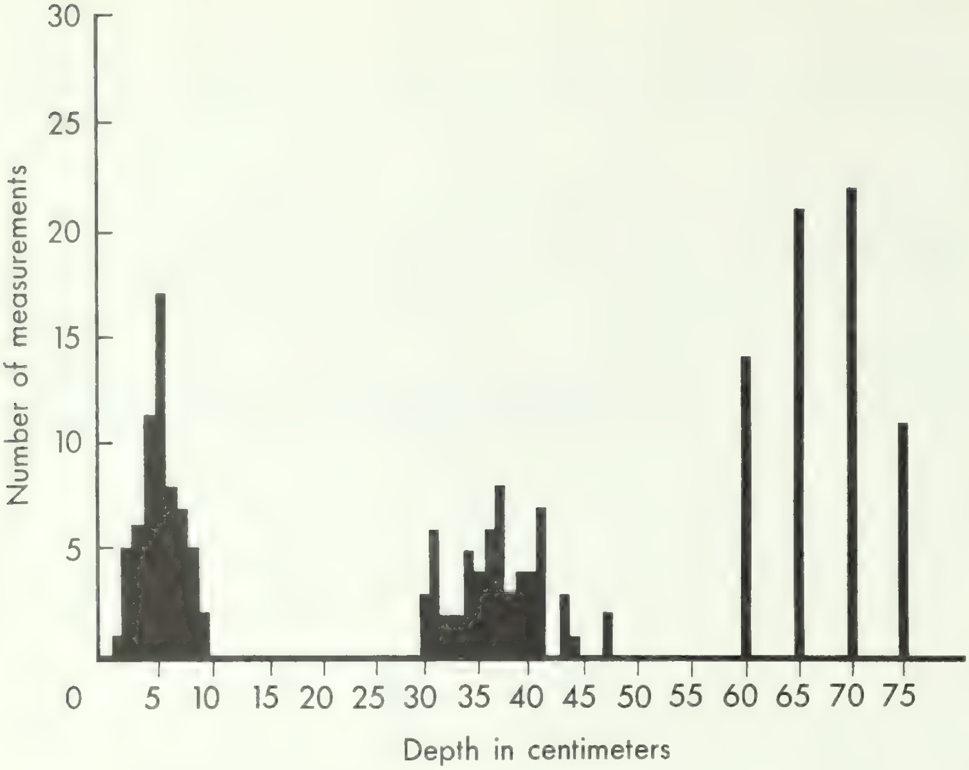


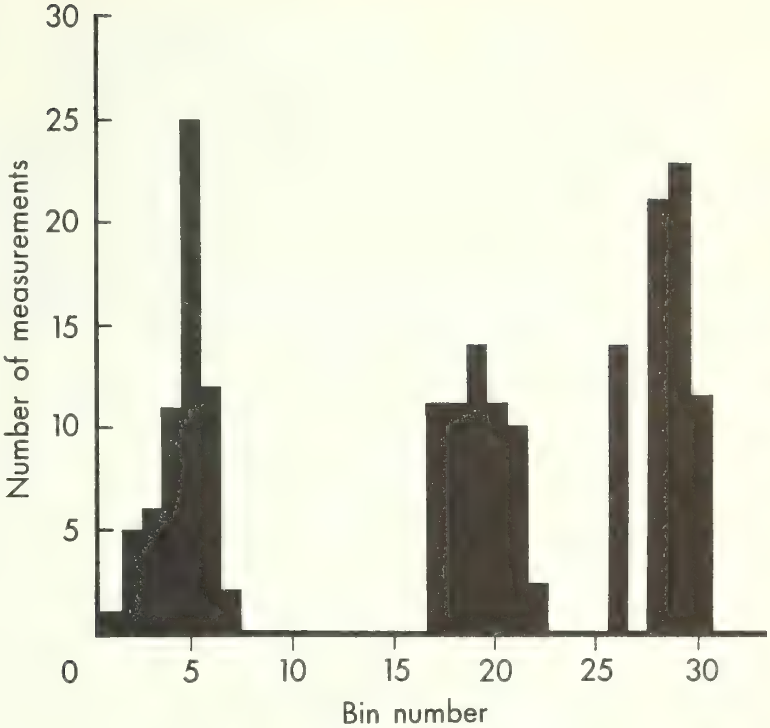
Figure 1.--Histogram of hypothetical depth-measurement data showing three superposed but distinctive groupings of depths.

We could have specified, for instance, that the spread of depths within which a measurement must fall to be included in a given bin should vary linearly with the median depth measurement for each bin. For example, we could increase by 0.1 cm the spread of depths for each successive bin, starting with the smallest, and construct a sequence of partition points as follows: 1.1, 2.3, 3.6, 5.0, 6.5, etc. This would le to a different histogram (fig. 2).

The procedure just outlined is somewhat arbitrary, but has a least heuristic justification. A measurement resulting in a recorded fuel depth of 2 cm is unlikely t change by 1 cm if repeated. But a measurement of 30 cm could easily become 29 or 31 if repeated. Not that the measurements would necessarily be in error, but that minor variations in windspeed, angle of solar illumination, etc., can result in small physi displacements of the fuel elements, and thus change the depth measurements. The grea the fuel depth, the greater the latitude for variations in depth, and the less import are such variations in determining fire behavior.

Two significant features of the revised histogram are that some of the vertical bars have become longer and that the patterns are almost fully contiguous within each group. My subjective view is that the lack of gaps between the vertical bars is an important factor in recognizing groupings. The vertical height of prominent bars als seems to attract the eye and to lead one to recognize the group with the longer bars more readily than the others. It is these two features which have been used as key elements in the algorithm described below, permitting a digital computer to sort raw data--a set of depth measurements—into groups.

:gure 2.--*Reconstruction of histogram of figure 1 using variable depth spreads for combining measurements.*



If the forms of the distribution functions of the various groups of data are known, much more sophisticated (and probably more accurate) method of extracting the groups ould be used. This would consist of the determination of the Fourier coefficients for series of distribution functions whose sum represents the histogram. Without owledge of even the form of the distribution functions, we are forced to turn to uder means of analysis.

The approach that was taken in formulating the algorithm can be described in the llowing terms:

1. A set of histograms is constructed, using different numbers of bins, with bin dths varying from essentially constant to rapidly increasing. The variation in bin dths is linear in the sense that the difference between widths of adjacent bins creases linearly with the ordinal numbers of the bins (as in the example above).

2. Each histogram is examined to determine the most prominent group represented) it. This is done by a thresholding procedure, analogous to laying a piece of paper er the bottom of the histogram, with a straight edge horizontal, and sliding it up e page until only one set of contiguous vertical bars project above the edge. On ing the paper downward, the lower the edge of the masking sheet can be brought be-re a disjoint vertical bar appears above the edge, the more prominent is the visible oup.

3. A numerical rating for each histogram is computed. This rating scores the togram on the basis of the degree of prominence of the prominent group and the pactness of the distribution included in the prominent group. This parameter is cribed below.

4. The membership in the most prominent group is determined. These measurements r averaged, then deleted from the measurement set. If sufficient data remain, the ire process is repeated to determine the next group.

The algorithm, as currently implemented, is repeated to determine three groups.

Equations

The equations used in implementing the steps outlined above are briefly developed below. Clearly, a major effort of the algorithm implementation was development of the logical framework and the bookkeeping of data manipulation. But, these are not german to the analytical content and will not be discussed here.

It is assumed here that the data are all integers. If the data were not in integ format, the values could be multiplied by the appropriate power of 10 to make them integers. The maximum value of 200 used here is arbitrary, but represents a reasonable upper limit to ground fuel depth in centimeters.

A. Bin Width Determination

If the largest (integer) value of the depth-measurement data set is H, the smalle S,[2] the number of bins into which the data are to be partitioned is N, and width of the j^{th} bin is W_j, then

$$\sum_{j=1}^{N} W_j = (H - S) \tag{1}$$

Since it is desired that the width of each successive bin be greater by a constant (a) than the preceding one, we have also

$$W_j = W_{j-1} + a, \text{ or } W_j - W_{j-1} = a \tag{2}$$

Summing equation (2) from j=2 to j=J gives the general form:

$$W_J = W_1 + (J - 1)a \tag{3}$$

Employing the closure constraint (equation 1) determines the value of the width-incre parameter, (a, as a function of W_1, the first bin width, and the other constants of t problem:

$$NW_1 + a\sum_{j=0}^{N=1} j = H - S; \quad a = (H - S - NW_1)/\ (N(N - 1)/2) \tag{4}$$

Note that when

$$W_1 = (H - S)/N \tag{5}$$

the widths remain constant. This is one case that is considered for each value of N The values of N and W_1 are selected so that a is nonnegative.

Values of N considered are incremented downward from Max (N), where

$$\text{Max}(N) = \text{Min}(200, [H - S]) \tag{6}$$

in steps of ΔN. This value is clearly arbitrary, but by experimentation, it was fou that

$$\Delta N = \text{Max}(1,\ 0.04\ \text{Max}(N)) \tag{7}$$

works adequately.

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[2] All zero measurements are purged at the outset.

Values of W_1 considered are incremented upward from $\mathrm{Min}(W_1)$, where

$$\mathrm{Min}(W_1) = (H - S)/N \tag{8}$$

arbitrary small steps of ΔW_1. The value used was decided by experimentation:

$$\Delta W_1 = 0.075\ \mathrm{Min}(W_1). \tag{9}$$

In its current configuration, the algorithm employs 22 values of N and 22 values W_1, generating 484 histograms each time a data set is fed to the algorithm. There a tradeoff between thoroughness and cost (running time). These numbers may in fact larger than necessary.

B. Numerical Rating of Histograms

We desire to establish a numerical rating scheme that will establish a ranking of e various histograms according to how well they exhibit the existence of a prominent ouping of measurements. From general considerations, this scheme should have the llowing features:

1. All other factors being equal, the greater the fraction of the total number data points in the histogram that fall into the prominent group (a group must have ntiguous vertical bars on a histogram presentation--the prominent group has the tall-t vertical bar), the greater should be the score.

2. As a means of establishing the relative degree of prominence of the prominent oups on the different histograms, the score of each should be reduced by the amount data hidden below the threshold established by the second-most-prominent group on ch histogram. So the number of bins contiguous in the prominent group, multiplied by e value of the threshold setting (expressed as a fraction of total data points) should deducted. This would leave the exposed fraction as the score.

3. To reduce the tendency of such a scoring scheme as outlined in the first two eps to favor ever-wider bin widths, some penalty must be assessed for using wider and ller bins. Else, in the limit, all data would be lumped into a few large, contiguous ns and the effort would fail its purpose. A satisfactory way to assess this penalty to divide the score defined in step No. 2 by the square root of the sum of the bin ths included in the prominent group.

Taken together, these three considerations lead to a scoring scheme that character-s group prominence in terms of tall, narrow, contiguous histogram bars that stand thest above the next-most-prominent group.

For those familiar with the concepts and terminology of radio communications, the nlog of the histogram rating score is a "signal-to-noise ratio." In this analogy, h fraction of the total number of depth measurements that lies in a contiguous group rjecting above the minimum threshold plays the part of a voltage signal. The noise ponent in the denominator is the square root of the total width of the bins included the above-threshold span. Extending this analogy one step further, the algorithm whole can be viewed as a procedure for generating a band-pass filter bank that imizes the signal-to-noise ratio defined in this way.

The equation used for scoring in the algorithm is:

$$S = \left(\sum_{i=J}^{K} n_i/N_T - (K - J + 1)f\right)/\left([1 + \delta + \sum_{i=J}^{K} W_i]\right)^{\frac{1}{2}} \tag{10}$$

where

S = histogram rating score

n_i = number of data points in bin number i

N_T = total number of data points in histogram

J = smallest ordinal number of bins in contiguous group, each of whose data poi count exceeds the threshold number

K = largest ordinal number of bins in contiguous group, each of whose data poin count exceeds the threshold number

f = threshold number expressed as a fraction of total data points in histogram. This is, fN_T is the data point count in a disjoint bin which sets the threshold

W_i = width of bin number i

δ = 0.075 W_1, merely a handy small quantity to eliminate spurious roundoff results when the denominator is rounded down to the next lower integer (t 1 is added for similar stability reasons).

$[x]$ = next smaller integer than x. Integer values are used because a unit represents the smallest possible change in a data point value, so the smallest meaningful change in bin width.

C. Sequence of Operations

The sequence of operations in the algorithm described is shown in the flow diagr of figure 3. Most of the logical and bookkeeping details have been suppressed and on the outline of operations is depicted.

Test Cases

Several test cases were used to perfect and exercise the computer program depict in figure 3. The purpose of these test cases was to establish the ability of the program to discern groups in artificial data generated by computer.

First, a background set of data were generated by selecting random integers between 0 and 100, inclusive. Then three additional sets of data were generated by selecting numbers at random from triangular distributions. The range of these added data points varied from trial to trial, but typically there would be one with a mean in the range 5-10, one with a mean in the range 15-20, and one in the range 60-70. The number of points in the background distribution was varied, as was the number of points in each of the triangular distributions superposed on the background. The purpose of these trials was to determine the point at which the algorithm could no longer discern the superposed triangular-distribution sets of data as distinctive groups against the noise background.

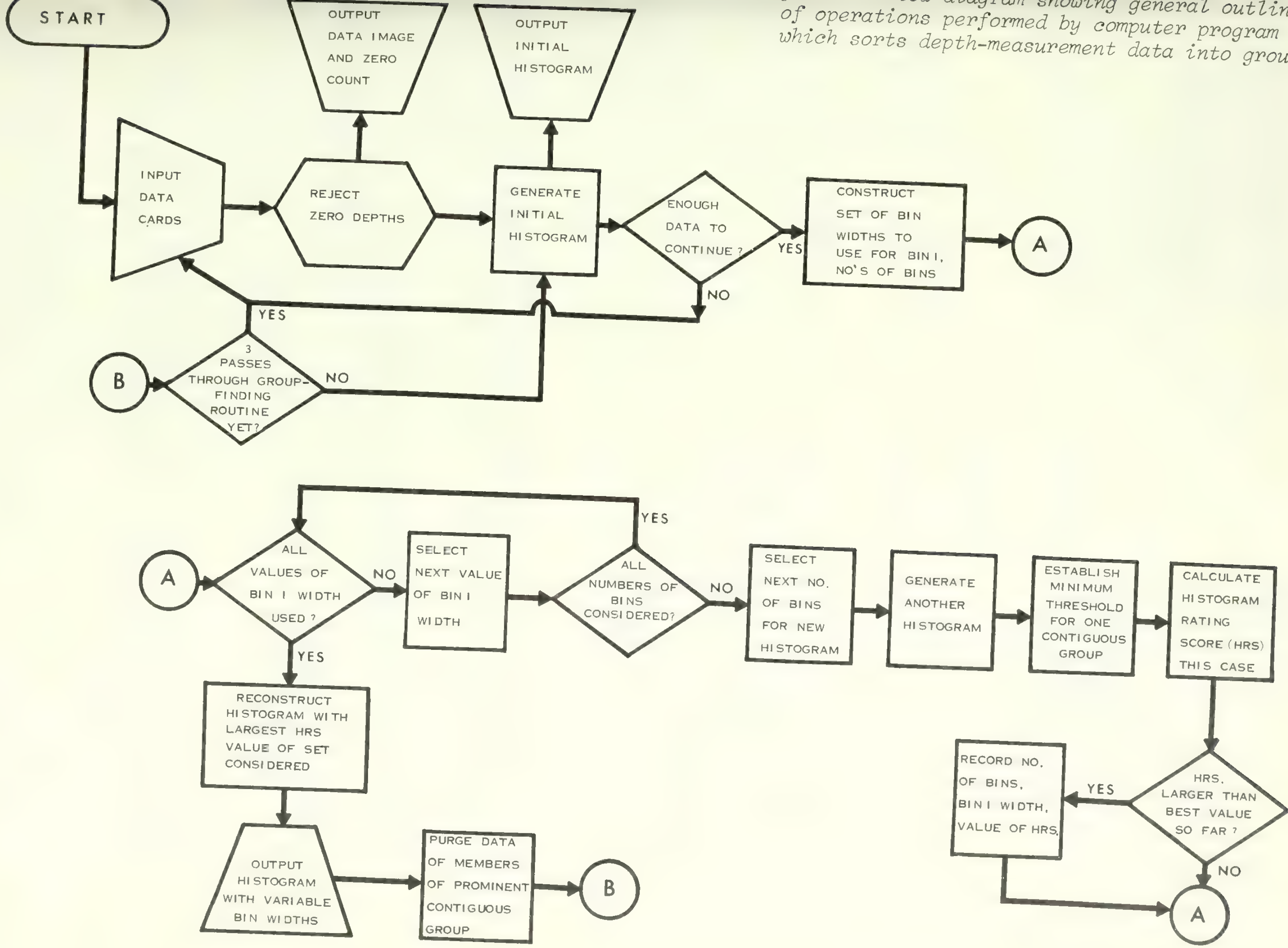

diagram showing general outline of operations performed by computer program which sorts depth-measurement data into groups.

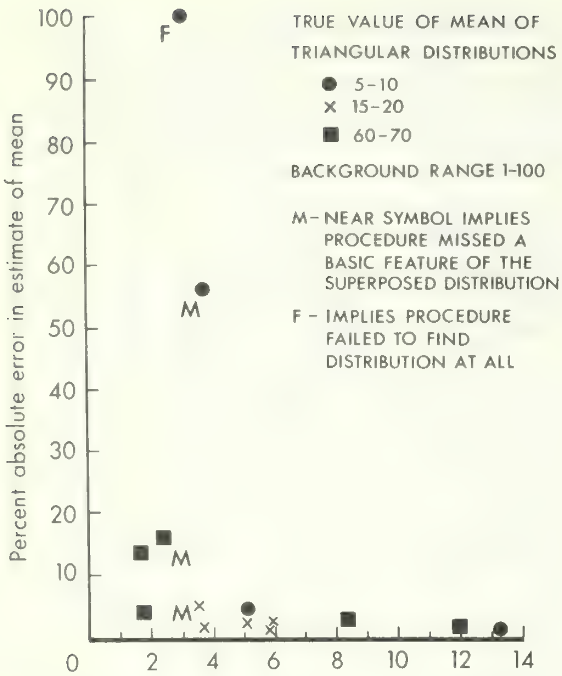

Figure 4.--Accuracy of estimation of distribution mean-versus-density of sample points from triangular distribution superposed on a flat distribution background noise.

The results of these tests were expressed as the percentage error in the estimation of the means of the superposed data groups. A parameter that characterizes the degree to which the superposed distribution is immersed in the background random data is the ratio, R, where

$$R = \frac{\text{Density of data points in range of added distribution}}{\text{Density of data points in the background data set}} \qquad (11)$$

The density of data points is here defined to be the total number of data points in a specified range of values, divided by the span of values in that range. For example, in the case represented by:

1. One hundred random data points in the range 0-100 (background)

2. Twenty data points added from a triangular distribution in the range 10-20

3. Suppose seven of the random data points also fell in the range 10-20; the density of data points in the range of the added distribution would be (20 + 7)/(20 - 10) = 2.7. The density of data points in the background data set would be (100)/(100 - 0) = 1.0, so R = 2.7/1.0 = 2.7.

This ratio is used as the abscissa of the scatter diagram plotted in figure 4. This figure shows all the test case exercises of the group-finding algorithm. The algorithm exhibits the tendency characteristic of its electrical analog discussed above, namely that it either works very well or fails dramatically, and that this failure is to be expected around a value of 3 or 4 for the ratio defined above.

Note that in all cases where the ratio R is greater than 4, the algorithm dis-
overed the superposed distributions and established their mean values with an error ess than 5 percent. Of the seven cases shown with R less than 4, two distributions ere recovered and their means established with accuracy better than 5 percent; one was ecovered but the mean was 13 percent in error; three were not recovered accurately, lthough their means were estimated (one with 5 percent error, one with 17 percent rror, and one with 57 percent); and one distribution was not recovered at all.

Because the performance of the algorithm closely paralleled that which would have een expected on the basis of the analogy that was used in constructing it, no further evelopmental work was done. The procedure has been used on actual field data as iscussed in the following section.

Field Data

As part of the White Cap Drainage Wilderness Fire Management Study,[3] fuel inventory ata were taken in 1971, 1972, and 1973. The data were reduced to punched-card formats, ategorized by timber cover type and by ecological (climax tree species/understory pecies) habitat type.[4]

We hoped to exercise Rothermel's spread rate model against these data to help stablish prescription guidelines for fire management in the study area. To do so equired not only fuel loading data but representative fuel depth estimates. Because he field data did not include the nature of the fuel that resulted in the recorded epths, some sorting procedure was necessary.

The automated procedure outlined above was used with these data, resulting in a set f depth-groups for each habitat type and timber type. These abbreviated data were hen reviewed for consistency and to see if the discovered distributions were really epresentative of the areas in question. Persons familiar with the general regions nder investigation could review these output data much more readily than they could the aw data.

In perhaps two-thirds of the cases reviewed, the depth-groupings recovered by the lgorithm were acceptable to the reviewers. In the other cases, the consensus was that he algorithm had failed to group the data in a meaningful way.

Some outputs are obviously spurious even to someone unfamiliar with the area under nvestigation. An example of such a result occurred in the grand fir timber type (dead uel) exercise. This data set consisted of 780 data points, ranging from zero (40 oints) to 200 cm, the greatest depth recorded (16 points). The algorithm first ecovered a grouping of 488 data points between 1 and 6 cm with an average depth of 0.46. This left 117 data points scattered between 18 and 200 cm, of which the bviously most prominent group was the concentration of 16 data points at 200 cm. This ast group was clearly spurious. On other exercises of the algorithm, more subtle but till spurious results were detected.

In most cases the algorithm appeared to have worked well in recovering one or two roups from the raw data. Frequently a third attempt yielded spurious results; often e data were insufficient to substantiate the existence of a third significant stinctive group.

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[3]Aldrich, David F., and Robert W. Mutch. Fire management prescriptions: a model an for wilderness ecosystems. USDA For. Serv., Intermt. For. and Range Exp. Stn. n preparation.)

[4]Pfister, R. D., B. L. Kovalick, S. A. Arno, and R. C. Presby. Forest habitat pes of Montana. USDA For. Serv., Intermt. For. and Range Exp. Stn. (In preparation.)

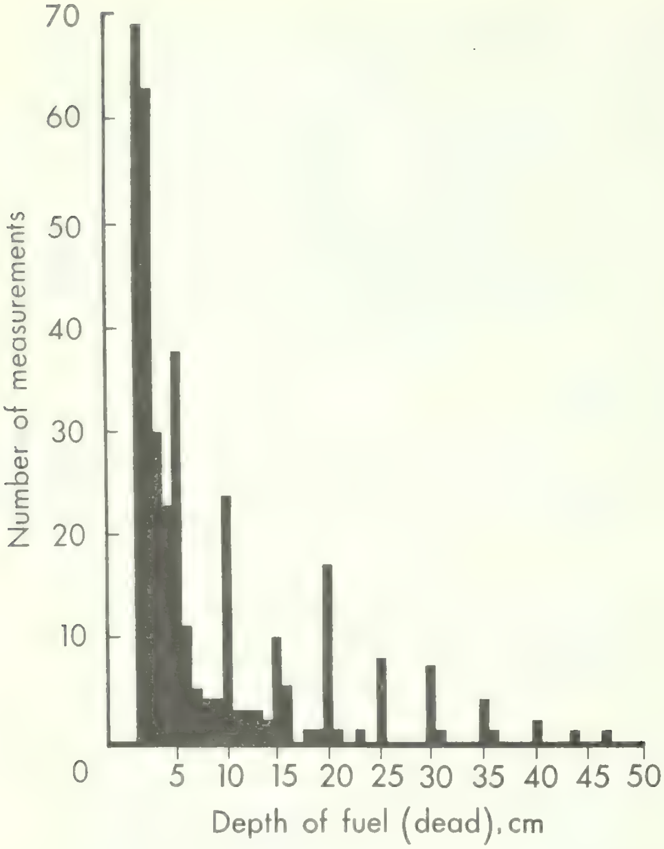


Figure 5.--Histogram of dead fuel depth measurements less than 50 cm taken in lodgepole pine timber type area of White Cap Drainage Wilderness Fire Management Study.

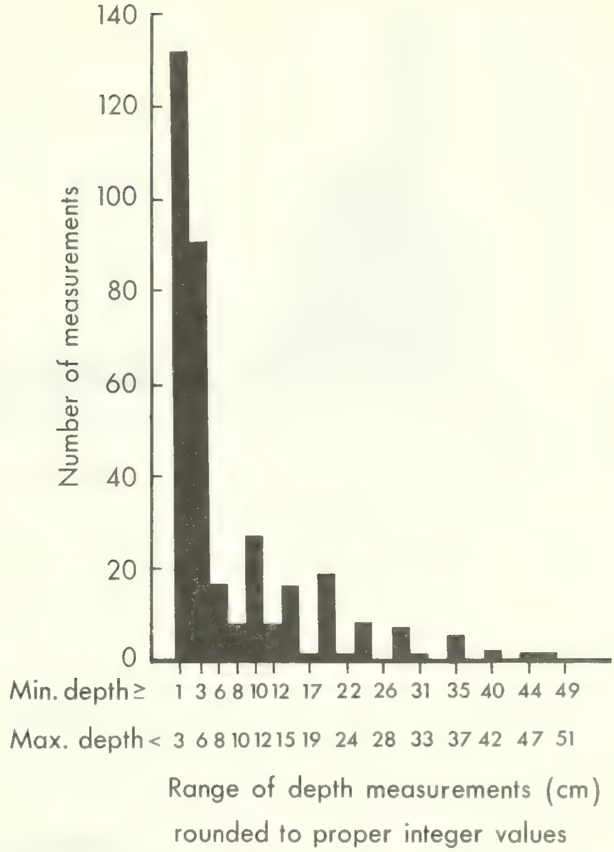
An example of such an exercise is the lodgepole pine timber type (dead fuel only) data from the cited study. These data consisted of 396 depth samples from zero to 190 cm, which included 35 zero-depth data points and the erroneous replication of 6 points. Of the 361 nonzero data points processed by the algorithm, all but 18 were measurements of less than 50 cm. These 18 points were widely scattered--the only concentrations being 3 points at 59-60 cm, and 3 at 90 cm (1 a spurious replicate). The less than 50-cm data are shown in the histogram of figure 5.

These data were processed by the algorithm, resulting in the tapered bin width histogram of figure 6. In this histogram, a prominent group is clearly evident. This group has an average depth of 2.54 cm and contains 223 data points.

The histogram of the remaining 138 (120 below 50 cm) data points is shown in figure 7. Once more these data were processed by the algorithm, resulting in the modified histogram shown in figure 8. Again, a contiguous group is clearly evident in the modified histogram, which shows all the data because the scale is so contracted here. The group apparent in the latter histogram averages 16.04 cm in depth and contains 118 data points.

The remaining 20 data points were processed again, resulting in a spurious group of 3 data points at 90 cm. This last group was rejected, but the other two groups were found to be acceptable as representative of needle litter-mat and fallen dead woody material, respectively.

igure 6.--Histogram of figure 5 as reconstructed by group-finding algorithm. Prominent group in first two bins contains 223 data points.



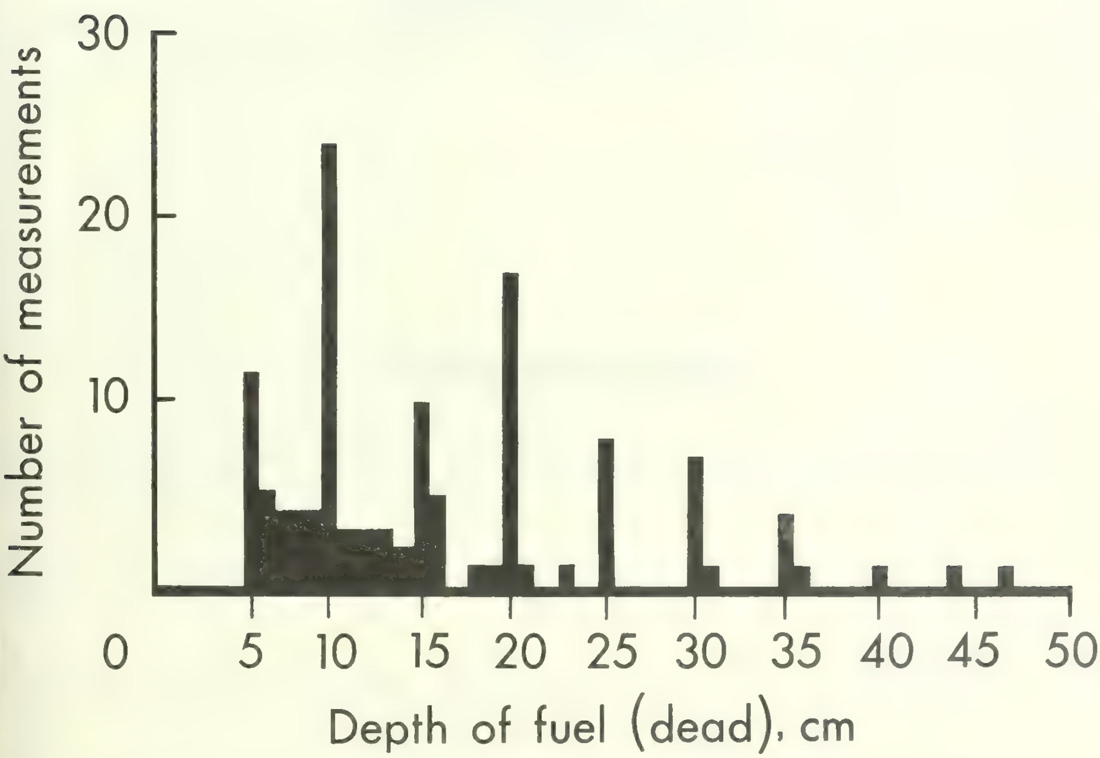


Figure 7.--Histogram of figure 5 after removal of 1-5 cm group.

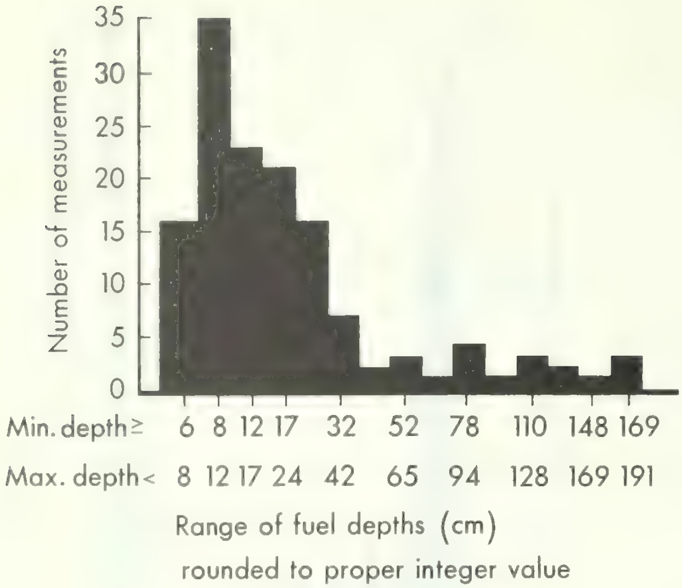


Figure 8.--Histogram of figure 7 (extended to include all data) as reconstructed by group-finding algorithm. Prominent group in first six bins contains 118 data points.

Computer processing of these data greatly expedited the chore of establishing representative depths for fuel arrays characteristic of various areas in the study region. Augmented by judicious review of the computer output, this method may be usef to other researchers holding similar sets of data.

Program Available

The computer program listing (FORTRAN IV) is given in the appendix. Copies of tl program may be obtained by contacting the author at the following address:

USDA Forest Service
Northern Forest Fire Laboratory
Drawer G
Missoula, MT 59801

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1971. A planar intersect method for sampling fuel volume and surface area. Fo1 Sci. 17(1):96-102.

Rothermel, Richard C.
1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115, 40 p.

USDA Forest Service.
1974. National fuel classification and inventory system: preliminary draft. 2 Division of Fire Management, Washington, D.C.

Van Wagner, C. E.
1968. The line intersect method in forest fuel sampling. For. Sci. 14:20-26.

APPENDIX

```
      PROGRAM GROUR (INPUT,OUTPUT,TAPE5=INPUT)

      COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL
      COMMON/INDATA/XIN(9600,3),NPLT(20),IDP(20,700),NAME(20,10),NCASES

88    CALL READER
      DO 100 NC = 1,NCASES
      NPL = NPLT(NC)
      PRINT 1,NC,(NAME(NC,J),J=1,10)
 1    FORMAT(1H1/10X*CASE NO.*I3/25X,10A8//20X*PLOTS INCLUDED AND DATA*)
2     FORMAT(I10,3F10.1)
      NX = NPTS = L = LL = 0
      FL = S = H = 0.
      DO 3 J = 1,200
      NO(J) = IDS(J) = 0
      FR(J) = W(J) = 0.
3     CONTINUE
      DO 4 J = 1,2000
      X(J) = 0.
4     CONTINUE
      DO 6 I = 1,NPL
      K = IDP(NC,I)
      DO 5 J = 1,3
      NX = NX + 1  $  X(NX) = XIN(K,J)
5     CONTINUE
6     PRINT 2,K,(XIN(K,J),J=1,3)
      NXS = NX
      CALL ZILCH(FLAG,ZEROES)
      NZO = NXS - NX
      PRINT 7,NXS,NZO,ZEROES,NX
7     FORMAT(//10X*THESE*I5*  DATA POINTS INCLUDE*I5*  WITH ZERO OR NEGA
     1TIVE VALUES*/10X*OR A FRACTION OF*F7.4*  OF THE DATA.  THESE HAVE
     2BEEN EXPUNGED, LEAVING*I5*  POINTS*)
      IF(FLAG.EQ.0.) GO TO 9
      PRINT 8
8     FORMAT(10X*THIS BEING TOO LITTLE DATA. THIS CASE IS SKIPPED*)
```

```
      GO TO 100
    9 CALL PULLER
  100 CONTINUE
      GO TO 88
      END




      SUBROUTINE READER

      COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL
      COMMON/INDATA/XIN(9600,3),NPLT(20),IDP(20,700),NAME(20,10),NCASES

C     THIS SUBROUTINE READS IN THE DATA FOR A SERIES OF RUNS.....
C     THE VARIABLES ARE PASSED TO THE FUNCTIONAL ROUTINES THROUGH COMMON

C     THE NUMBER OF CASES TO BE RUN IS     NCASES.... COUNTED ON INPUT HERE

C     THE NUMBER OF PLOTS PER CASE IS      NPLT(J)    J IS THE CASE NUMBER

C     THE NAME OF THE RUN IS GIVEN AS     NAME(J,I)

C     THE IDENTITY OF PLOT NUMBER K FOR CASE J IS    IDP(J,K)

C     THE DEPTH SAMPLE INPUT DATA ARE ENTERED INTO ARRAY XIN(I,J)
```

```
      SUBROUTINE ZILCH(FLAG,ZEROES)

C  ..  FLAG=0, NO TROUBLE. =1. NOT ENOUGH POINTS LEFT TO ANALYZE

      COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL

      NEX = 0  $  FLAG = 0.  $  ZEROES = 0.
      DO 10 J = 1,NX
      IF(X(J).LE.0.) GO TO 10
      NEX = NEX + 1  $  X(NEX) = X(J)
 10   CONTINUE
      NEXT = NEX + 1
      DO 20 J = NEXT,2000
      X(J) = 0.
 20   CONTINUE
      NGONE = NX-NEX  $  ZEROES = FLOAT(NGONE)/FLOAT(NX)
      IF(NEX.LE.4)  FLAG = 1.
      NX = NEX  $  RETURN  $  END


      SUBROUTINE THRESH(FLAG,FINC)

      COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL

      FLAG=0.  $  NL=NO(1)
      DO 1  J = 2,NPTS
      IF(NO(J).GT.NL) NL = NO(J)
 1    CONTINUE
      NL = NL-1  $  NUP=0  $  FINC=0.  $  NA=NO(2)  $  NB=NO(NPTS-1)
      IF(NL.LE.0)  GO TO 10
      DO 2 J = 1,NPTS
      IF(NO(J)-NL) 2,22,222
```

```
222  NUP = NUP + 1 $ IDS(NUP) = J $ FINC = FINC + FR(J) $ GO TO 2
 22  IF(J.EQ.1) GO TO 32
     IF(J.EQ.NPTS) GO TO 42
     IF((NO(J-1).GE.NL).OR.(NO(J+1).GE.NL))222,2
 32  IF(NA.GE.NL) 222,2
 42  IF(NB.GE.NL) GO TO 222
  2  CONTINUE
     NTHRU = IDS(NUP) - IDS(1) + 1
     IF(NTHRU.NE.NUP)  GO TO 10
     NL = NL - 1
     IF(NL.GT.0) GO TO 4
     L=IDS(1)  $  LL=IDS(NUP)  $  FL=FLOAT(NL+1)/FLOAT(NX)  $  RETURN
  3  NL = NL -1
     IF(NL.LE.0) GO TO 7
  4  NUP = 0  $  FINC = 0.
     DO 5 J = 1,NPTS
     IF(NO(J)-NL) 5,55,555
555  NUP = NUP + 1 $ IDS(NUP) = J $ FINC = FINC + FR(J) $ GO TO 5
 55  IF(J.EQ.1) GO TO 35
     IF(J.EQ.NPTS) GO TO 45
     IF((NO(J-1).GE.NL).OR.(NO(J+1).GE.NL)) 555,5
 35  IF(NA.GE.NL) 555,5
 45  IF(NB.GE.NL) GO TO 555
  5  CONTINUE
     NTHRU = IDS(NUP) - IDS(1) + 1
     IF(NTHRU.EQ.NUP)  GO TO 3
  6  NL = NL + 1
     IF(NL.GE.NX) 10,8
  7  NL = NL + 1
     FL=FLOAT(NL)/FLOAT(NX)  $  L=IDS(1)  $  LL=IDS(NUP)
     IF(FL.LT.0.)  FL = 0.
     RETURN
  8  NUP = 0  $  FINC = 0.
     DO 9 J = 1,NPTS
     IF(NO(J)-NL) 9,99,999
999  NUP = NUP + 1 $ IDS(NUP) = J $ FINC = FINC + FR(J) $ GO TO 9
```

```
99   IF(J.EQ.1) GO TO 39
     IF(J.EQ.NPTS) GO TO 49
     IF((NO(J-1).GE.NL).OR.(NO(J+1).GE.NL)) 999,9
39   IF(NA.GE.NL) 999,9
49   IF(NB.GE.NL) GO TO 999
 9   CONTINUE
     NTHRU=IDS(NUP)-IDS(1)+1  $  FL=FLOAT(NL)/FLOAT(NX)
     IF(NTHRU.NE.NUP)  GO TO 10
     L = IDS(1)  $  LL = IDS(NUP)  $  RETURN
10   FLAG = 1.  $  RETURN  $  END



     SUBROUTINE HGRAM

     COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL

     DO 1 J = 1,NPTS
     NO(J) = 0  $  FR(J) = 0.
1    CONTINUE
     XMAX = S  $  XNX = FLOAT(NX)
     DO 4 I = 1,NPTS
     XMIN = XMAX  $  XMAX = XMIN + W(I)
     IF(I.EQ.NPTS)  XMAX = 1.00101*XMAX
     DO 3 J = 1,NX
     T = X(J)
     IF((T.LT.XMIN).OR.(T.GE.XMAX))  GO TO 3
     NO(I) = NO(I) + 1
3    CONTINUE
4    FR(I) = FLOAT(NO(I))/XNX
     RETURN  $  END
```

```
      SUBROUTINE WINDOW(FLAG)

      COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL

C     FLAG = 0. NO TROUBLE. 1.SINGULAR DISTRIBUTION. 3. NO SOLUTION

      XMIN = S  $  XMAX = H  $  FLAG = 0.
      IF((NPTS.LE.1).OR.((S+W(1)).GE.H))  GO TO 3
      WN = FLOAT(NPTS)
      A = (XMAX - XMIN - WN*W(1))*2./(WN*(WN-1.))
      IF(A.LE.0.)  GO TO 4
      DO 2 J = 2,NPTS
      W(J) = W(J-1) + A
    2 CONTINUE
      RETURN
    3 NPTS = 1  $  FLAG = 1.  $  RETURN
    4 FLAG = 2.  $  RETURN  $  END




      SUBROUTINE TUNER(SNB)

      COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL

      DIMENSION TS(22),FIN(22),W1(22),IL(22),IH(22),NBINS(22),SN(22)
      NB = 0 $ NPS = 0 $ SNB = 0. $ W1B = 0.
      W1(1) = W(1)  $  DW = .075*W(1)
      DO 1 J = 2,22
      W1(J) = W1(J-1) + DW
    1 CONTINUE
      DO 9 J = 1,22
      W(1) = W1(J)
      DO 2 K = 1,22
      TS(K) = FIN(K) = SN(K) = 0.
```

```
      IL(K) = IH(K) = 0
2     CONTINUE
      NPMX=(H-S)/W(1)  $  NPMX=MINO(NPMX,200)  $  NPMX=MAXO(NPMX,3)
3     CALL WINDOW(FLAG)
      IF(FLAG.EQ.1.)  GO TO 9
      IF(FLAG.NE.2.)  GO TO 4
      NPMX = NPMX - 1
      IF(NPMX.LT.3) 9,3
4     DN = .04*FLOAT(NPMX)  $  ND = DN
      IF(ND.LT.1)  ND = 1
      NPTS = NPMX + ND
      DO 7 K = 1,22
      NPTS = NPTS - ND  $  NBINS(K) = NPTS
      IF(NPTS.LT.3)  GO TO 7
      CALL WINDOW(FLAG)
      IF(FLAG.EQ.2.) GO TO 7
      IF(FLAG.EQ.1.) GO TO 6
      CALL HGRAM
      CALL THRESH(FLG,FINC)
      IF(FLG.NE.0.)  GO TO 7
      IL(K) = L  $  IH(K) = LL  $  FIN(K) = FINC  $  TS(K) = FL
      WIDE = 0.
      DO 5 I = L,LL
      WIDE = WIDE + W(I)
5     CONTINUE
      WIDE = WIDE + 1.+DW
      NWIDE = WIDE  $  WIDE = FLOAT(NWIDE)
      SN(K)=(FIN(K)-TS(K)*FLOAT(LL+1-L))/SQRT(WIDE)  $  GO TO 7
6     IL(K) = 1 $ IH(K) = NPTS $ FIN(K) = 1. $ TS(K) = 0.
      SN(K) = 1./SQRT(H-S)
7     CONTINUE
      DO 8 K = 1,22
      IF(SN(K).LE.SNB)  GO TO 8
      SNB = SN(K) $ WIB = W1(J) $ NB = NBINS(K)
8     CONTINUE
9     CONTINUE
```

```
      NPTS = NB  $  W(1) = W1B
      CALL WINDOW(FLAG)
      IF(FLAG.NE.0.)  GO TO 10
      CALL HGRAM
      RETURN
 10   PRINT 11
 11   FORMAT(///10X*TROUBLE IN TUNER ROUTINE*)
      SN5 = -1.  $  RETURN  $  END




      SUBROUTINE PULLER

      COMMON X(2000),W(200),NO(200),FR(200),L,LL,S,H,IDS(200),NPTS,NX,FL

      DIMENSION NAST(80)
      DATA(NAST=80(1H*))
      NPULLS = 0
100   S = X(1)  $  H = X(1)  $  NPULLS = NPULLS + 1
      DO 1 J = 2,NX
      T = X(J)
      IF(T.LT.S) S = T
      IF(T.GT.H) H = T
 1    CONTINUE
      DB=.0025*(H-S)  $  H=H+DB  $  S = S - DB
      PTS=H-S $ NPTS=PTS+1.01 $ NPTS=MAX0(NPTS,2) $ NPTS=MIN0(NPTS,200)
      W(1) = (H-S)/FLOAT(NPTS)
 2    CALL WINDOW(FLAG)
      IF(FLAG.EQ.2.)  GO TO 4
      CALL HGRAM
      PRINT 10
 10   FORMAT(1H1/10X*INITIAL HISTOGRAM OF DATA*//
     15X*BIN*5X*COMPARTMENT LIMITS*5X*NUMBER*5X*RELATIVE*/
     25X*NO.*5X*LOWER - TO - UPPER*5X*POINTS*5X*FREQUENCY*//)
```

```
 20  FORMAT(I8,F10.2,F13.2,I9,F15.5,5X,80A1)
     X2 = S
     DO 3  J = 1,NPTS
     X1=X2  $  X2=X1+W(J)  $  NA=NO(J)  $  NA=MIN0(NA,80)
     IF(NA.LE.0)  GO TO 3333
     PRINT 20,J,X1,X2,NO(J),FR(J),(NAST(K),K=1,NA)
     GO TO 3
3333 PRINT 20,J,X1,X2,NO(J),FR(J)
 3   CONTINUE
     GO TO 5
 4   W(1) = .9999999*W(1)  $  GO TO 2
 5   CALL TUNER(SNR)
     IF(SNR.LE.0.)  GO TO 101
     CALL THRESH(FLAG,FINC)
     IF(FLAG.EQ.1.) GO TO 101
     PRINT 30,FINC
 30  FORMAT(1H1//10X*HISTOGRAM WITH TAPERED COMPARTMENTS REVEALS GROUP*
    1//10X*PROMINENT CONTIGUOUS GROUP CONTAINS*F7.5* OF POINTS*///
    15X*BIN*5X*COMPARTMENT LIMITS*5X*NUMBER*5X*RELATIVE*/
    25X*NO.*5X*LOWER - TO - UPPER*5X*POINTS*5X*FREQUENCY*//)
     X2 = S
     DO 6 J = 1,NPTS
     X1=X2  $  X2=X1+W(J)  $  NA=NO(J)  $  NA = MIN0(NA,80)
     IF(NA.LE.0)  GO TO 6666
     PRINT 20,J,X1,X2,NO(J),FR(J),(NAST(K),K=1,NA)
     GO TO 6
6666 PRINT 20,J,X1,X2,NO(J),FR(J)
 6   CONTINUE
     PRINT 40,L,LL
 40  FORMAT(//5X*NOTE GROUP IN COMPARTMENTS*I4* TO*I4)
     XLOW = S  $  ML = L-1
     IF(L.EQ.1) GO TO 8
     DO 7 J = 1,ML
     XLOW = XLOW + W(J)
 7   CONTINUE
 8   XHIGH = XLOW
```

```
      DO 9 J = L,LL
      XHIGH = XHIGH + W(J)
9     CONTINUE
      K = 0  $  NEW = 0  $  SUM = 0.
      DO 12 J = 1,NX
      IF((X(J).GE.XLOW).AND.(X(J).LE.XHIGH))  GO TO 11
      K = K + 1  $  NEW = NEW + 1  $  X(K) = X(J)  $  GO TO 12
11    SUM = SUM + X(J)
12    CONTINUE
      AV = SUM/FLOAT(NX - NEW)
      PRINT 50, AV
50    FORMAT(//5X*AVERAGE OF INCLUDED DATA POINTS (NOW REMOVED)*F15.5)
      NX = NEW
      PRINT 60, NEW
60    FORMAT(//5X*TOTAL REMAINING POINTS*I5)
      IF((NPULLS.LE.2).AND.(NX.GT.4))  GO TO 100
      IF(NPULLS.LT.3) PRINT 80
80    FORMAT(10X*INSUFFICIENT DATA TO CONTINUE SEARCH FOR GROUPS*)
      RETURN
101   PRINT 70
70    FORMAT(///10X*UNABLE TO DETERMINE GROUPING ON THIS DATA*)
      RETURN  $  END
```


☆ U.S. GOVERNMENT PRINTING OFFICE: 1975 — 677-328 / 2 REGION NO. 8

ALBINI, FRANK A.
1975. A computer algorithm for sorting field data on fuel depths. USDA For. Serv. Gen. Tech. Rep. INT-23, 25 p. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Describes an algorithm for separating depth measurements of forest fuels into distinct groups. Presents a flow chart and FORTRAN listing. Copies of computer program are available from author.

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AN ATTEMPT (AND FAILURE) TO CORRELATE DUFF REMOVAL AND SLASH FIRE HEAT

Frank A. Albini

USDA Forest Service
General Technical Report INT-24, 1975
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
Ogden, Utah 84401

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ABSTRACT

A detailed analysis is made of field data taken during a program of experimental broadcast burning of logging slash in northwestern Montana. An unsuccessful attempt was made to relate the amount of F and H layer duff burned out to the quantity of heat released by the slash burning, as estimated by theory. Inadequacies in the data and pitfalls of procedure are indicated in hopes of assisting experiment design in future work of this nature.

BACKGROUND

From the spring of 1967 to the fall of 1969, approximately 1,000 acres of Douglas- larch, spruce, and fir logging slash were broadcast burned experimentally in two onal Forest areas of western Montana--Miller Creek, northwest of Kalispell, and an Ridge, west of Superior. Forty-six research plots of 2-1/2 acres each were es- ished within the fires at Miller Creek (Flathead National Forest) and twenty-seven re plots at Newman Ridge (Lolo National Forest). The research plots were extensively ntoried and instrumented to quantify various aspects of fuel loading, environmental itions, and fire effects.

One of the significant statistical findings[1] of the research effort was a strong elation between the reduction in duff depth and (1) upper duff moisture content (2) Buildup Index. Because the heat load (Btu/ft^2 of surface) delivered to the as measured by water-can analogs (George 1969) was also found to be strongly lated to these two parameters, it was natural to speculate that the heat load on ite played a causal role in duff removal.[1]

Duff depth reduction or removal is often an objective of prescribed burning ase regrowth may be influenced by exposure of soil to seed. To help in formulating ng prescriptions, an effort was made to develop a relationship between heat re- d per unit area by burning of the slash fuels and the reduction in depth of duff ved on the site. The effort failed. The purpose of this report is to summarize unsuccessful attempt in the hope that future research will profit from an under- ing of the pitfalls encountered.

theory was developed that relates the heat flux onto the surface of the duff to the amount of duff removed (depth reduction), using the duff weight loading isture profile as parameters.

ttempts were made to calculate the heat released by slash burning on the various Using the fuel loadings by size class and species, Rothermel's (1972) fire model was exercised to obtain heat release rates. Another theory was developed[2] to predict the amount of large fuel that would be burned out in a slash-type omplex and so predict the heat released.

o apply these theories required an intensive review of the study data. For e, the greatest quantity of potential heat release in logging slash resides in avier fuels. A small error in the estimate of the loading of large pieces can the total heat release potential of all the fine fuels. So, a review of ement and data-reduction procedures was also required.

the following sections, the measurement and data-reduction methods are reviewed and accuracy of data is assessed. The theories are presented later, unsuccessful comparisons of predictions and measurements follow.

---

[1] illiam R. Beaufait, Charles E. Hardy, and William C. Fischer. Broadcast burning h-fir clearcuts: the Miller Creek-Newman Ridge study. USDA For. Serv. Res. Pap. (in preparation).

[2] rank A. Albini. Computer-based models of wildland fire behavior: a users' USDA For. Serv. Gen. Tech. Rep. INT-___(in preparation).

DUFF DEPTH DETERMINATION

Two methods were used to determine duff depth reduction: (1) Direct measurement at three spots near each of 66 sample points, before and after the burn; (2) installation of 8-inch spikes, driven into the soil so that the head of the spike was at the upper duff surface prior to the fire, with measurement of the exposed spike length after the fire. Seventy-two spikes per plot were emplaced. The sixty-six 1-meter-long transects were the points at which the direct depth measurements were made, and because preburn and postburn transect locations were not necessarily the same, considerable internal variability was noted in that data. So the spike measurements were preferred for analysis of duff reduction.[3]

Measurements were recorded to the nearest centimeter, so an average duff depth before and after the burn was available, probably accurate to within 0.5 centimeter or less; these data should adequately represent average duff depth on the site, although the sample standard deviation was a large fraction of the mean in some cases (spot checked).

FUEL LOAD DETERMINATION

Fuel load was determined by size class, using the line transect method (Beaufait and others 1974), with sixty-six 1-meter transects the standard number per 2-1/2-acre plot. Inventories were taken before and after each plot was burned. Woody intercepts by species and size class (diameter <1 cm, 1-10 cm, >10 cm) were recorded and the diameters of the intercepted pieces of diameter greater than 10 cm were recorded. The data were reduced to histogram format for the larger sizes; that is, the weight loading was computed for diameters of 10 to 20, 20 to 30, 30 to 40 cm, and so on.

These data were inadequate to establish accurately the loadings of the larger size classes.

The reduction of data taken by the line-intercept method rests on the plausible assumption that the fuel pieces are horizontal, randomly oriented, and randomly scatter

[3]William R. Beaufait, and others, op. cit.

on the ground. Such a distribution of pieces leads to a formula for the expected number of centerline intercepts per unit length of transect of the form

$$N' = (2/\pi)(\nu L) \tag{1}$$

where

N' = expected number of intercepts per unit transect length

ν = average number of fuel pieces per unit area of plot

L = length of fuel pieces.

This formula is valid whether the transect is one long, continuous transect or is composed of many short, randomly placed transects, so long as the fuels are randomly distributed.[4] The average weight loading for the size class in question is simply

$$W = \nu\rho(\pi D^2/4)L = \rho(\pi^2 D^2/8)N' \tag{2}$$

where

W = average weight loading of size class D (e.g., lb/ft^2)

ρ = weight density of fuel

D = diameter of fuel pieces.

The difficulty with the data in question arises from the fact that the observed variable, N', is Poisson distributed (Beaufait and others 1974), so a great deal of variability is to be expected.

The statistical problem here can best be posed in terms of the total number of intercepts (of a given size class) achieved in sampling the plot. Let the number be J. If the number of such intercepts *to be expected* is I, then the probability distribution for the sample outcome, J, is

$$P_I(J) = (I^J/J!)\exp(-I) \tag{3}$$

Table 1 is a brief tabulation of this distribution, and the summary at the bottom reveals the problem inherent in dealing with small numbers of intercepts. Note that in all cases shown, the probability of an error of at least 50 percent is high.

For the preburn and postburn inventories taken at Miller Creek, the average number of intercepts per meter of transect for the larger fuel sizes was as shown in table 2. Also shown is the average number of intercepts for a 66-meter total transect length.

[4] If the fuel elements are all alined in one direction (lying along the fall line), a small correction factor is required, assuming the transects are randomly oriented. The variance increases slightly with respect to the mean in that case.

Table 1.--*Probability of achieving J intercepts when I are to be expected and error introduced when J interpreted to represent the value of I*

Number of Intercepts achieved, *J*		Expected number of intercepts, *I* 1	2	3	4	5
	Probability	0.368	0.135	0.050	0.018	0.007
	Error (percent)	(-100)	(-100)	(-100)	(-100)	(-100)
1		0.368	0.271	0.149	0.073	0.034
		0	(-50)	(-67)	(-75)	(-80)
2		.184	.271	.224	.147	.084
		(+100)	0	(-33)	(-50)	(-60)
3		.061	.180	.224	.195	.140
		(+200)	(+50)	0	(-25)	(-40)
4		.015	.090	.168	.195	.175
		(+300)	(+100)	(+33)	0	(-20)
5		.003	.036	.101	.156	.175
		(+400)	(+150)	(+67)	(+25)	0
6		.001	.012	.050	.104	.146
		(+500)	(+200)	(+100)	(+50)	(+20)
7		--	.003	.022	.060	.104
			(+250)	(+133)	(+75)	(+40)
8		--	.001	.008	.030	.065
			(+300)	(+167)	(+100)	(+60)
9		--	--	.003	.013	.036
				(+200)	(+125)	(+80)
10		--	--	.001	.005	.018
				(+233)	(+150)	(+100)
Probability that error is zero:		.368	.271	.224	.195	.175
Probability that error is at least 50 percent:		.632	.729	.384	.450	.260

Table 2.--*Average number of fuel intercepts by transect for Miller Creek prescribed burns*

	Fuel diameter (cm) 1-10	10-20	20-30	30-40
	INTERCEPTS PER METER			
Preburn	6.74	0.498	0.293	0.067
Postburn	1.85	.340	.171	.040
	INTERCEPTS IN 66 METERS			
Preburn	444.80	32.900	19.300	4.400
Postburn	122.10	22.400	11.300	2.600

The implication of these numbers in terms of the accuracy of weight loading estimation is shown in figure 1. In constructing figure 1, we have used the approximation that the estimate of the mean surface density is a statistic with Gaussian distribution (unbiased). Figure 1 is interpreted as follows: The ordinate is the tolerance, expressed as a percentage, in the estimation of the loading of any fuel size class. The "confidence level" is the probability that the sample estimate of the loading will fall within the tolerance band of the true value. The abscissa then gives the expected number of intercepts that must be achieved to obtain that confidence level and tolerance. For example, to be correct 95 percent of the time in asserting that the estimated loading is within ±30 percent of the true value, the expected number of intercepts must be 42. At that number of expected intercepts, the estimated loading will be within ±25 percent of the true value 90 percent of the time, within ±16 percent for 70 percent of the time, and within ±10 percent for 50 percent of the time.

The statistical design of the sampling procedure (Beaufait and others 1974) emphasized the taking of data for the fine fuels, and represents a sophisticated yet practical approach to that problem. The accuracy of the fine fuel loadings was generally very good. But, the accuracy of the estimates of weight loading by large size classes in the plots burned was generally poor. In fact, in nearly half the plots the postburn inventories showed higher loadings of large fuels (≥20 cm) than the preburn inventories. This is to be expected given the magnitude of errors anticipated in dealing with small samples.

Five plots in the Miller Creek series were sampled (preburn only) much more extensively than all the others. On units 111, 207, 308, 401, and 405 there were 231 1-meter transects. The improvement in large fuel loading estimation accuracy is substantial for these units. More data on these plots are presented later.

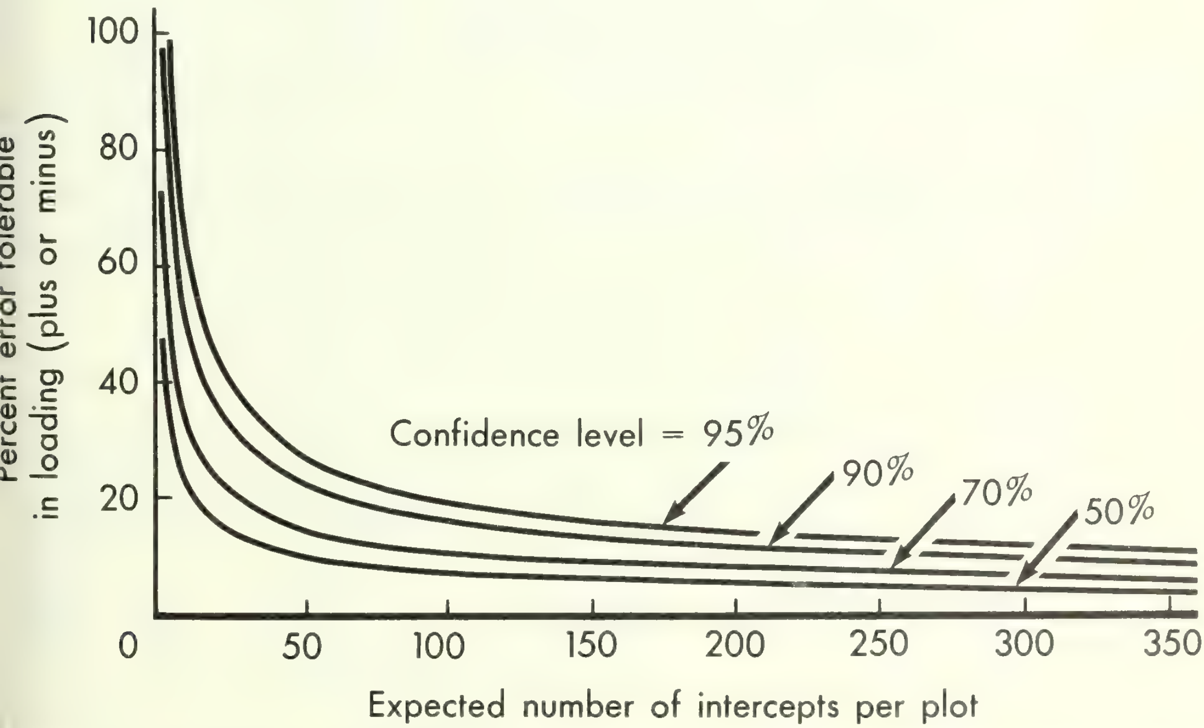


Figure 1.--Confidence level and error in estimating the loading by fuel size class on Miller Creek and Newman Ridge slash burn plots.

DUFF MOISTURE MEASUREMENTS

The critical role of duff moisture in influencing the amount of duff burned out has long been recognized. Duff moisture was measured in each of the plots in the Miller Creek/Newman Ridge series just prior to burning. Three points were sampled in each plot. The measurements were made for upper and lower duff mantle strata at each point.

Had these measurements indicated uniformity of duff moisture over the plot area, three samples for estimating mean upper and lower duff moisture content would probably have been adequate. That such was not the case is reflected in table 3, which shows the upper and lower duff moisture contents for the three sample points on the five intensively inventoried plots. Note that only in units 401 and 405 did the trend of moisture content with depth maintain the same mathematical sense for the three samples. At 11 of the 15 points, the duff moisture increased with depth, and at 4 it decreased. The author cannot explain why the mathematical sense should not have been uniform for each plot.

In unit 401, the lower duff moisture exceeded the range of the data format for two of the points, so are not accurately known.

Because these are small-sample statistics, conclusions must be drawn with great caution. But the sample standard deviations are so large compared to the mean values that clearly we are dealing with a locally variable quantity and should not infer a single moisture value (or profile) as representative of the entire unit. Table 3 shows the sample standard deviations. Only unit 405 seems "well behaved" with respect to these data.

In future field measurement efforts, causally related variables that exhibit such variability must be sampled in juxtaposition and treated as ordered sets of data.

Table 3.--*Upper and lower duff moisture content (percent) for the three sample points taken on units intensively inventoried for fuel loading, Miller Creek slash burns*

Unit No. (aspect)	Point 1		Point 2		Point 3		Average		Standard deviation	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
111 (N)	41	10	33	56	27	88	33.7	51.3	7.0	39.2
207 (E)	24	46	38	47	81	68	47.7	53.7	29.7	12.4
308 (S)	21	46	12	6	95	31	42.7	27.7	45.5	20.2
401 (W)	70	*	23	*	47	83	46.7	>93.7	23.5	**
405 (W)	21	66	23	58	28	43	24.0	55.7	3.6	11.7

* Moisture content exceeded 99 percent, recorded as 99.
** Cannot estimate accurately.

DUFF WEIGHT LOADING

The weight loading of the duff mantle (F and H layers combined) was inferred from a correlation function relating depth of duff and weight loading (Beaufait and others 1974). These regressions were developed using 25 samples each from various plots of each slope exposure. The regression equations developed[5] are in terms of the dry weight of duff in a 5-inch-diameter cylinder as a function of the depth in millimeters. They are, for the various exposures:

$$\text{(NORTH)}\quad W = -10.412 + 1.298D \tag{4}$$

$$\text{(EAST)}\quad W = 15.331 + 1.372D \tag{5}$$

$$\text{(SOUTH)}\quad W = -16.055 + 1.559D \tag{6}$$

$$\text{(WEST)}\quad W = -5.415 + 1.369D \tag{7}$$

Because the equations and the data to which they were fitted agree so well, the representation of duff weight load from the average depth over the plot is probably adequate.

Slash Fuel Characteristics and Duff Loading on Five Units

The intercept-count data for the five Miller Creek units were reduced to estimates f loading by size class, using the site-specific relative frequency distributions of ree species and the foliage-weight/twig-weight ratio for each species. These data re available in tabular form from the author on request. The list of fuels on each lot included 40 to 50 entries. The total dry weight fuel loading, average duff depth nd loading before burning, and the average duff depth after burning for the five ntensively inventoried plots are shown in table 4. Derived quantities, such as fuel

Table 4.--*Fuel and duff loadings on five units, Miller Creek*

Unit No.	Dry slash load	Average duff depth		Preburn average duff load
		Preburn	Postburn	
	Lb/ft²	----------*cm*----------		*Lb/ft²*
111	6.60	4.21	1.11	0.714
207	5.35	3.01	0.56	.914
308	6.26	3.18	.50	.688
401	5.81	3.35	1.35	.584
405	4.56	4.29	.44	.820

[5]Rodney A. Norum. Unpublished data compiled in support of "Broadcast Burning in Larch-Fir Clearcuts: the Miller Creek-Newman Ridge Study," by Beaufait, Hardy, and Fischer. Data on file at the Northern Forest Fire Laboratory, Missoula, Montana.

loadings, heat release, etc., are given in British units for consistency with most American forestry literature. Data transcribed from the study material are left in the metric form in which they were recorded to facilitate comparison with the unpublished source data.

In terms of slash fuel loadings, there is little disparity among units in table 4, but in terms of load distribution by size class (table 5), the differences are considerable. The differences can be largely attributed to species variations on the sites. Unit 111 was predominantly fir and spruce; 207, fir and Douglas-fir/larch; 308 and 405, Douglas-fir and larch; and 401, fir with a mixture of Douglas-fir, larch, spruce, and yew. The other major fire-influencing parameters are wind, slope, fuel bed depth, and fuel moisture. These parameters are tabulated in table 6 for compariso

The data presented in table 6, including the breakdown of loading by size class and species, and species-dependent fuel properties, were used in Rothermel's (1972) fire spread model to obtain fire spread characteristics. The data were also used in the theory that attempts to predict the amount of large fuel which will be burned and the heat released on the site.[6]

Although it was possible to compare the large-fuel-burnout theory with carefully inventoried slash burns in Canada (Stocks and Walker 1972), it was not possible to test the duff-burnout theory against independent data. The duff-burnout theory is briefly described below.

Table 5.--*Total slash loading by size class on five units, Miller Creek*

Unit No.	Size class (diameter in cm)						
	Foliage	0 - 1	1 - 10	10 - 20	20 - 30	30 - 40	40 - 50
	Dry loading (Lb/ft²)						
111	0.1135	0.0923	0.3509	1.2842	2.7815	1.7143	0.2648
207	.0828	.0733	.7456	1.0598	2.1217	.6924	.5723
308	.0388	.0447	.5494	1.2585	3.0565	.9174	.3032
401	.1075	.0950	.7699	.7991	1.4754	1.5072	1.0539
405	.0458	.0561	.5174	1.3825	1.9667	.6625	0

Table 6.--*Fire-influencing parameters on five units, Miller Creek*

Unit No.	Fuel moisture: Needles	Fuel moisture: 0 - 1 cm	Fuel moisture: 1 - 10 cm	Slope	Estimated wind (20 ft)	Average depth
	- - - - - - Percent		*- - - - - -*	*Percent*	*Mi/h*	*Ft*
111	5.1	7.5	25.5	20	12.7	2.69
207	17.1	16.8	27.8	60	6.6	2.76
308	21.6	19.2	22.2	10	8.9	2.22
401	7.7	12.5	19.5	10	9.1	3.06
405	4.5	6.5	18.3	10	18.3	2.16

[6]Frank A. Albini, op. cit.

DUFF-BURNOUT THEORY

The basic tenets of the theory proposed here for duff burnout under the influence of an external heat load on the surface of the duff mantle are:

1. If moisture content is less than some critical value, M_x, duff will burn with no external heat input.

2. The external heat load is applied slowly enough that the burnout of duff being dried by the external heat source keeps pace with the drying. As the external heat source dries the upper surface of the duff to moisture M_x, the surface layer burns. The external energy input is required only to dry the duff to moisture M_x.

3. The burning of the surface of the duff does not dry out the duff below the surface significantly, but supplies the heat needed to completely desiccate and ignite only successive infinitesimal surface layers.

4. The duff mantle is of uniform bulk density (based on dry weight).

5. The profile of moisture with depth is exponential in form.

This last assumption is clearly arbitrary. The other assumptions can be defended on heuristic or anecdotal evidence, but not on experimental data of which the author is aware.

The equations relating the heat load imposed on the duff surface (Q) to the amount of duff burned out depend upon the value of the initial surface duff moisture (M_s) and the duff moisture at the soil-duff interface (M_o) as well as the critical moisture content (M_x) for burning. This can easily be seen by considering the various logical possibilities:

1. <u>Surface moisture less than bottom moisture</u> ($M_s \leq M_o$)

   a. $M_o \leq M_x$

      In this case, the entire duff mantle would be burned without any added external heat load; $Q = 0$.

b. $M_s \leq M_x$, $M_o > M_x$

In this case, the upper duff would burn, without assistance from external drying heat, down to the point at which the moisture equals the critical value. Let this depth be X_1, and the initial duff depth be D. Because we have assumed the moisture profile to be exponential, we can express these relationships in terms of the moisture-profile parameter, α:

$$M_o \exp(\alpha D) = M_s \tag{8}$$

$$M_o \exp(\alpha X_1) = M_x \tag{9}$$

from which

$$X_1/D = 1 - \ln(M_s/M_x)/\ln(M_s/M_o) \tag{10}$$

Now the application of an external heat load, Q, could dry the remaining duff, starting at the upper surface (X_1) down to some final depth (X_F) from whatever moisture it was originally ($M_o \exp(\alpha X)$) to the critical value (M_x). If the bulk density of the duff is ρ_b, and the heat necessary to vaporize a unit mass of water is L, then the implicit heat balance is expressed by:

$$\int_{X_F}^{X_1} (M_o \exp(\alpha X) - M_x)\rho_b L\,dX = Q \tag{11}$$

Using equation (8) to eliminate the profile parameter, α, and equation (10) to eliminate X_1, equation (11) can be written as:

$$Q/\rho_b DLM_x = \left(1 - \frac{M_s}{M_x}\left(\frac{M_s}{M_o}\right)^{(X_F/D\ -\ 1)}\right)/\ln\left(\frac{M_s}{M_o}\right) - \left(1 - \frac{X_F}{D} - \ln\left(\frac{M_s}{M_x}\right)/\ln\left(\frac{M_s}{M_o}\right)\right) \tag{12}$$

Here we use the dimensionless group $Q/\rho_b DLM_x$ to gage the external heat required. To calculate the heat input per unit area, Q, required to burn off the fraction $(1 - X_F/D)$ of the duff load, we must multiply the dimensionless parameter by the product of the duff loading ($\rho_b D$) and the latent heat parameter (LM_x).

c. $M_s > M_x$

In this case, external drying heat is required before even the surface will burn. Expressing the same heat balance as represented by equation (11) we have:

$$\int_{X_F}^{D} (M_o \exp(\alpha X) - M_x)\rho_b L\,dX = Q \tag{13}$$

which is simply expressed as:

$$Q/\rho_b DLM_x = \left(\frac{M_s}{M_x}\right)\left(1 - \left(\frac{M_s}{M_o}\right)^{(X_F/D\ -\ 1)}\right)/\ln\left(\frac{M_s}{M_o}\right) - \left(1 - \frac{X_F}{D}\right) \tag{14}$$

2. Surface moisture greater than bottom moisture ($M_s \geq M_o$)

a. $M_s \leq M_x$

Here the entire duff mantle would burn out without additional external heat; $Q = 0$.

b. $M_s > M_x$, $M_o < M_x$

Here the upper surface would not burn without the addition of external drying heat, but if sufficient heat were added to burn the duff down to the point at which the moisture equals the critical value, the duff would burn all the way to the soil surface without any additional external heat. So there is a "break point" at depth X_2, where

$$X_2/D = 1 - \ln(M_s/M_x)/\ln(M_s/M_o) \tag{15}$$

which is formally the same as equation (11). For depths of burnout that do not reach X_2, the necessary heat balance is given by equation (13), which leads to equation (14).

For depths of burn that reach the level X_2, the heat input required is obtained by using $X_F = X_2$ in equation (14), which reduces to:

$$Q/\rho_b DLM_x = \left(\frac{M_s}{M_x}\right)\left(1 - \left(\frac{M_o}{M_s}\right)^{\ln(M_s/M_x)/\ln(M_s/M_o)}\right)/\ln\left(\frac{M_s}{M_o}\right) + \ln\left(\frac{M_s}{M_x}\right)/\ln\left(\frac{M_s}{M_o}\right) \tag{16}$$

c. $M_o \geq M_x$

In this case, the duff will burn only with the addition of external heat, and the heat balance relationship leads once again to equation (14).

The equations given just above were programed for the Hewlett-Packard 9820 calculator for calculation of $Q/\rho_b DLM_x$ as a function of $(1 - X_F/D)$, the fractional reduction in duff depth. In order to interpret the relationships that can be calculated, however, we must establish either:

1. one duff moisture profile representative of each unit; or

2. the fractions of total unit area that are represented by the three measured moisture profiles for each unit.

From the data presented in table 3, the first alternative is clearly untenable. The data simply will not support any such inference. The second alternative is also unattractive because one can do no better than to assign to one-third of each unit one of the three profiles sampled on that unit. Although such an assumption is consistent with the data, it is not verifiable. Nevertheless, in the absence of better data, the latter approach was taken.

Table 7.--*Computed values of heat load necessary to produce observed levels of duff depth reduction on five Miller Creek units*

Unit No.	Observed average duff depth reduction	Preburn duff load	Duff load remaining	Duff load reduction	Computed value of $Q/\rho_L DLM_x$			
					$M_x=0.3$	$M_x=0.4$	$M_x=0.5$	$M_x=0.6$
	[illegible]	- - - - - - - Lb/ft^2	- - - - - -		- - - [illegible]	- - - - - -		
111	[illegible]	0.714	0.188	0.526	0.180	0.025	0.000	0.000
207	.814	.914	.170	.744	.705	.423	.235	.134
308	.843	.688	.108	.580	.730	.420	.230	.111
401	.597	.584	[illegible]	.349	.495	.246	.105	.034
405	.897	.820	.084	.736	.182	.037	.000	.000

Because the equations relating heat load and duff depth reduction yield the parameter $Q/\rho_b DLM_x$ directly, it was necessary to compute the fractional duff depth reduction for each plot, for a given level of heat load, by "cross plotting" the direct relationships. That is, for each value of $Q/\rho_L DLM_x$ the average value of $(1 - X_v/D)$ was determined by interpolating that value for each of the three moisture profiles for each unit and averaging the results to obtain an estimator for the average value of $(1 - X_v/D)$ for the unit, were it subjected to the given heat load.

To further complicate the problem, the resulting curves are functions of the assumed value of M_x. For that reason, table 7 shows several entries for the normalized heat load ($Q/\rho_L DLM_x$) required to produce the observed fractional duff depth reduction. Also shown in table 7 are the duff weight loadings ($\rho_L D$) for the five units. For the purpose of these calculations, the unknown lower duff moistures on unit 401 were assumed to be 100 percent.

HEAT LOAD ON THE SITE AND DUFF REMOVAL

Using the data presented in table 7, one can estimate the heat load required to produce the observed amount of duff depth reduction.

The heat load on each site was investigated through the use of water-can analogs (George 1969; and footnote 1). These data can be compared to the heat loads calculated from the duff burnout measurements. Water-can weight losses are summarized in table 8. Assuming the average water-can weight loss on each site to be proportional to the heat load on that site, we can pick a standard site and normalize the data to obtain a relative measure of heat load. For this we use "standard unit" number 405, which had the highest water-can weight loss. The relative heat loads calculated (normalized to unit

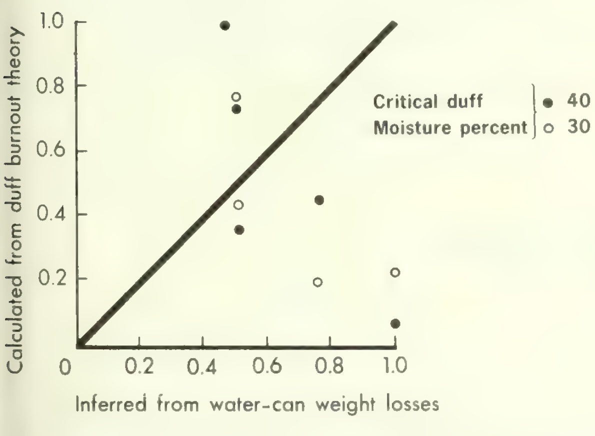
Table 8.--*Summary of water-can weight loss data for five intensively inventoried Miller Creek Units. Initial weight of water for all measurements is 3,400 grams*

Unit No.	Number of reliable measurements	Average remaining water	Average water loss	Standard deviation
		- - - - - - - - - -	*Grams*	- - - - - - - - - -
111	35	2,212	1,188	465
207	36	2,672	728	368
308	33	2,616	784	408
401	35	2,601	799	371
405	33	1,790	1,610	365

207 [table 7]) are compared to the relative water-can losses on a scatter diagram (fig. 2). Figure 2 also compares the relative heat loads calculated (table 7) and the relative reaction intensities computed using the Rothermel spread model.

In all cases, calculated heat loads do not agree with the other measures of heat output. The scatter diagrams of figure 2 show that the calculated heat load requirements do not agree with water-can weight losses. There is better agreement between the reaction intensity trend and the water-can weight loss trend than between either trend and calculated heat load. Table 9 shows the water-can weight loss-versus-reaction intensity trend. Also shown in table 9 is a calculated value of the heat released based on the theory of burnout of the larger fuel elements and the average duff depth loss data taken from table 4.

It is not surprising that Rothermel's reaction intensity does not agree well with data for either duff removal or water-can loss because the reaction intensity, computed for a spreading fire, represents principally the rate of combustion of the fine fuels that propagate the flame front. In slash burns, the greatest part of the heat load is contributed by larger fuel elements that are strongly discounted by the spread model algorithm.



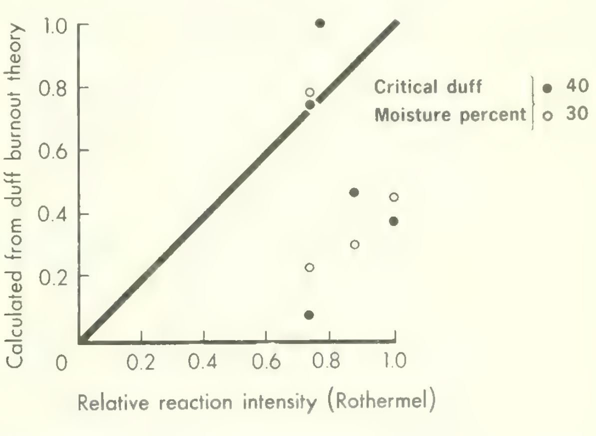


Figure 2.--Comparison of relative heat loads on five Miller Creek units, as determined from water-can weight loss data (upper) and reaction intensity (lower) and from duff-burnout theory.

Table 9.--*Heat load measures and duff burnout for five intensively inventoried Miller Creek units*

	Unit number				
	111	207	308	401	405
Average duff depth loss, cm	3.10	2.45	2.68	2.00	3.85
Average water-can weight loss, g	1,188	728	785	799	1,610
Rothermel's reaction intensity, Btu/ft^2/min	3,197	2,809	2,699	3,658	2,670
Computed total heat load from slash burnout (theory), Btu/ft	31,900	21,800	27,000	24,000	17,300
Computed relative heat load by slash burnout (theory)	1.00	.682	.845	.751	.541
Heat load required from duff-burnout theory, Btu/ft^2					
30 percent critical moisture	38.6	193.3	150.7	86.7	44.8
40 percent critical moisture	7.14	154.7	115.6	57.5	12.1
Computed relative heat load required (duff-burnout theory)					
30 percent critical moisture	.199	1.00	.779	.449	.232
40 percent critical moisture	.462	1.00	.747	.372	.077

COMPARISON WITH VAN WAGNER'S FORMULA

For calculating duff consumed by fire under standing timber, Van Wagner (1972) proposed a formula that correlated well with the data for which it was generated. Supported by a simple theory, the equation is heuristically appealing. Rewritten in British units, his formula becomes:

$$W_D = 0.1926\ (1.418 - M)/(0.1774 + M) \qquad (17)$$

where

W_D = dry weight loading of duff consumed, lb/ft^2

M = average moisture content of the duff (fraction of dry weight).

Applying this equation directly to the Miller Creek data poses two difficulties:

1. The equation predicts burning of duff under standing timber, where the duff mantle frequently represents a major part of the consumable fuel. On this basis, the equation should underestimate the amount of duff consumed when burned under a loading of logging slash.

2. The duff layer moisture, assumed to be uniform in Van Wagner's formula, is onuniform (vertical and horizontal gradients exist) for the areas considered here.

Nevertheless, the formula provides a point of departure, and offers the possibility f establishing a lower limit for duff consumed. Calculations were based on three ifferent "average moistures" per plot, and the average of three duff consumption preictions calculated. This was done because of the high variability of the moisture levels table 3). Because the upper and lower duff moistures were frequently greatly different, n exponential vertical variation of moisture content was again assumed, so the massverage moisture content at any point is given by:

$$\overline{M} = \frac{1}{D} \int_{0}^{D} M(x)dx = (M_s - M_o)/\ln(M_s/M_o) \tag{18}$$

able 10 shows the values of the moisture contents so averaged, the predicted duff conumption values for each point, the average predicted duff consumption, and the observed alues. As expected, the formula underestimated the degree of duff consumption in each ase.

The results shown in table 10 indicate that the differences between the observed nd predicted average values do not correlate at all with either Rothermel's reaction ntensity or the predicted total heat load from slash burning (table 9). So, it is not ossible to attribute "additional" duff burnout to these measures of external heat input.

Table 10.--*Comparison of duff consumption observed with that predicted by Van Wagner's formula for five Miller Creek slash burns*

it .	Average moisture content (exponential vertical variation assumed)			Predicted duff consumption				Observed values
	Point 1	Point 2	Point 3	Point 1	Point 2	Point 3	Average	
	- - - - - - -Percent	- - - - - - -		- - - - - - - - Lb/Ft^2	- - - - - - - -			
11	22.0	43.5	51.6	0.581	0.309	0.251	0.380	0.526
27	33.8	42.3	74.3	.404	.319	.141	.288	.744
38	31.9	8.7	57.2	.426	.970	.217	.538	.580
41	84.1*	52.4*	63.3	.109	.245	.187	.180	.349
45	39.3	37.8	35.0	.346	.361	.390	.366	.736

* Lower duff moisture content assumed to be 100 percent.

DISCUSSION

Data presented in tables 9 and 10 support the following conclusions:

1. Calculations of the heat required to cause the amount of duff burnout observed) not correspond well with any of the measures of heat released (water-can weight loss, othermel's reaction intensity, or a theoretical estimate of slash burn heat release).

2. The average duff depth-loss does correlate well with the water-can weight los

3. Van Wagner's duff consumption formula underestimates the degree of duff burno observed, as expected; but the degree of disagreement cannot be correlated to measures of slash fire heat release, either.

Factors that must be considered in evaluating these relationships (or lack thereo include:

1. The theory used to predict the slash burn heat release is weak and has not be adequately tested.

2. The duff moisture data from which the required heat loads were calculated may be inadquate to provide a realistic appraisal of duff moisture content.

3. The theory behind the "required heat load" calculations is untested and may be inadequate.

4. The water-can weight loss may be generated by the burning of duff rather than by the burning of the slash fuel overburden. As such, it would represent only another means of estimating the duff load removal, not a measurement of heat released above th duff itself.

In summary, the analysis performed provided no additional theoretical relationshi that might be useful in projecting the findings of these experiments to different situations. Gaps in the data prevented the confirmation or refutation of any of the theoretical relationships developed. The purpose of this report is to document these relationships and to capture the data. Perhaps future research can profit from the information presented here.

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OXFORD: 332.2: 114.354.
KEYWORDS: slash, duff, heat release, intensity, broadcast burning, fuel sampling, fuel loading, logging slash, duff removal, duff burning.

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TIME STUDY TECHNIQUES FOR LOGGING SYSTEMS ANALYSIS

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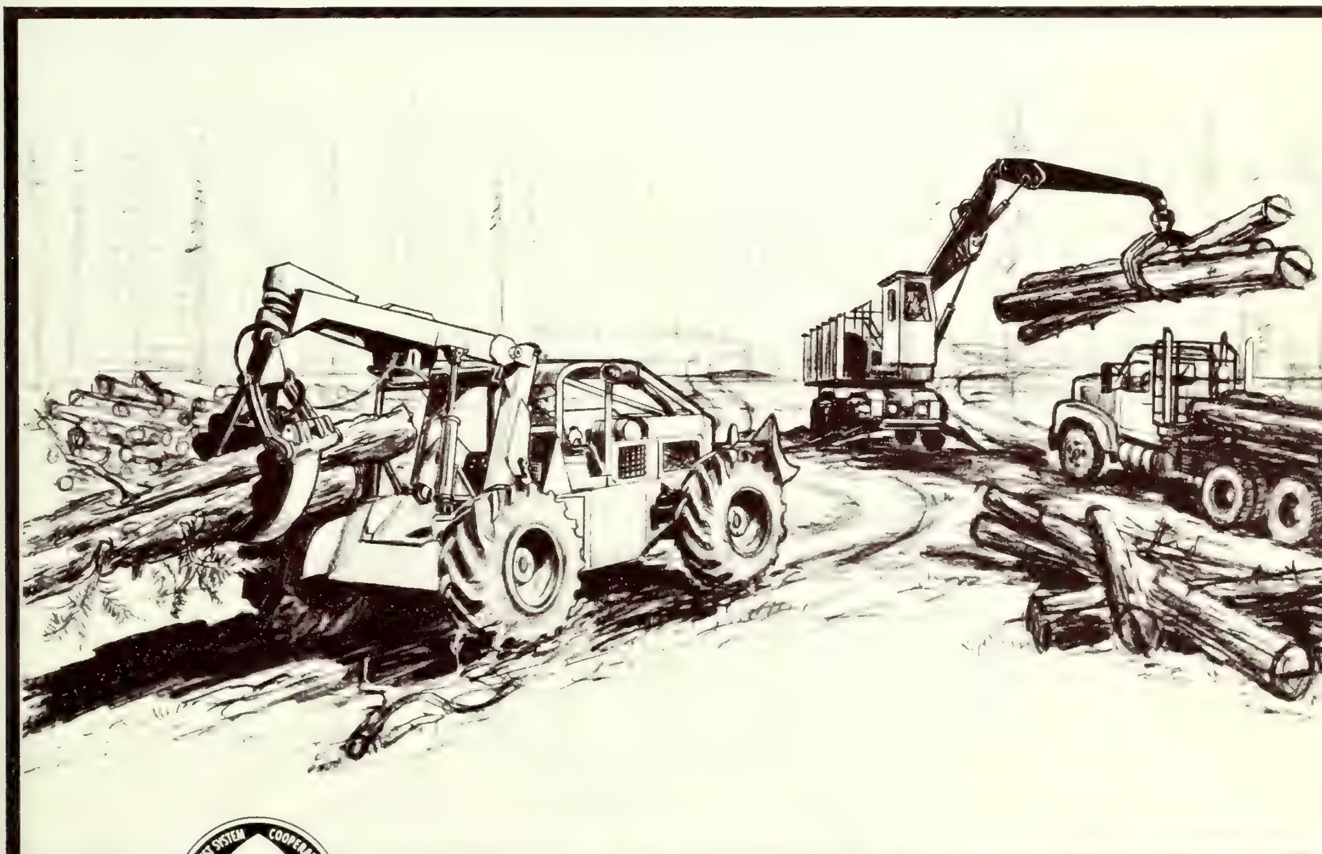

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ABSTRACT

Analysis of logging operations generally entails data gathering. Frequently, these data are in the form of elemental time studies. Prior to collecting such data, operations must be explicitly defined and broken into events. Also, an efficient manner of recording and processing the data must be designed. The USDA Forest Service research work unit of Intermountain Station at Bozeman, Montana, has been engaged in recent years in a comprehensive logging systems analysis study. Together with other research work units, this unit has developed, field tested, and refined a system to gather time and motion study data on logging operations. Techniques and forms employed for certain types of operations are presented in this publication. Forms for other types of logging operations are to be issued as appendices to this publication.

INTRODUCTION

For several years, the USDA Forest Service research work unit FS-3701 located at zeman, Montana, has been working on a comprehensive study of logging systems. The jective of the program has been to develop (utilizing the systems approach) an alytical model together with accompanying methodologies for evaluating alternative mber harvesting systems, given a set of parameters such as timber characteristics, rrain features, and management objectives. Figure 1 illustrates the major functions the research effort.

In order to obtain the information necessary to analyze logging systems, operations re defined, data were collected, and computer analysis was undertaken. These activ- ies are represented by blocks 4, 5, and 6 in figure 1. Block 4 illustrates the five sic subsystems being studied: roadbuilding, felling and bucking, skidding/yarding, ading, and hauling. Detailed flow process charts and work element descriptions have en or are being developed for each subsystem. A site-terrain classification scheme s also been devised to categorize the equipment and physical characteristics in which ch subsystem operates. Data are collected and then entered into an information orage and retrieval system as shown in block 5 of figure 1, and further detailed in gure 2. The system involves eight levels of data processing:

Level 1: Data Acquisition

Level 2: Data Codification

Level 3: Data Transcription

Level 4: Creation of Data Files

Level 5: File Acquisition

Level 6: Data Manipulation

Level 7: Computation and Analysis

Level 8: Generation of Output.

This handbook addresses itself to the first two levels of processing: acquisition d codification of data. Specifically, it presents part of a standardized data col- ction system developed by RWU FS-INT-3701 in conjunction with other research stations. lustrated herein is the use of standardized time study forms for a typical logging tuation: mechanized felling, skidding with a rubber-tired skidder, and loading. rms, together with flow process charts and other accompanying material that would be cessary to collect information on these operations, are presented. The forms for her types of operations are to be released as appendices to this publication.

LOGGING SYSTEMS ANALYSIS

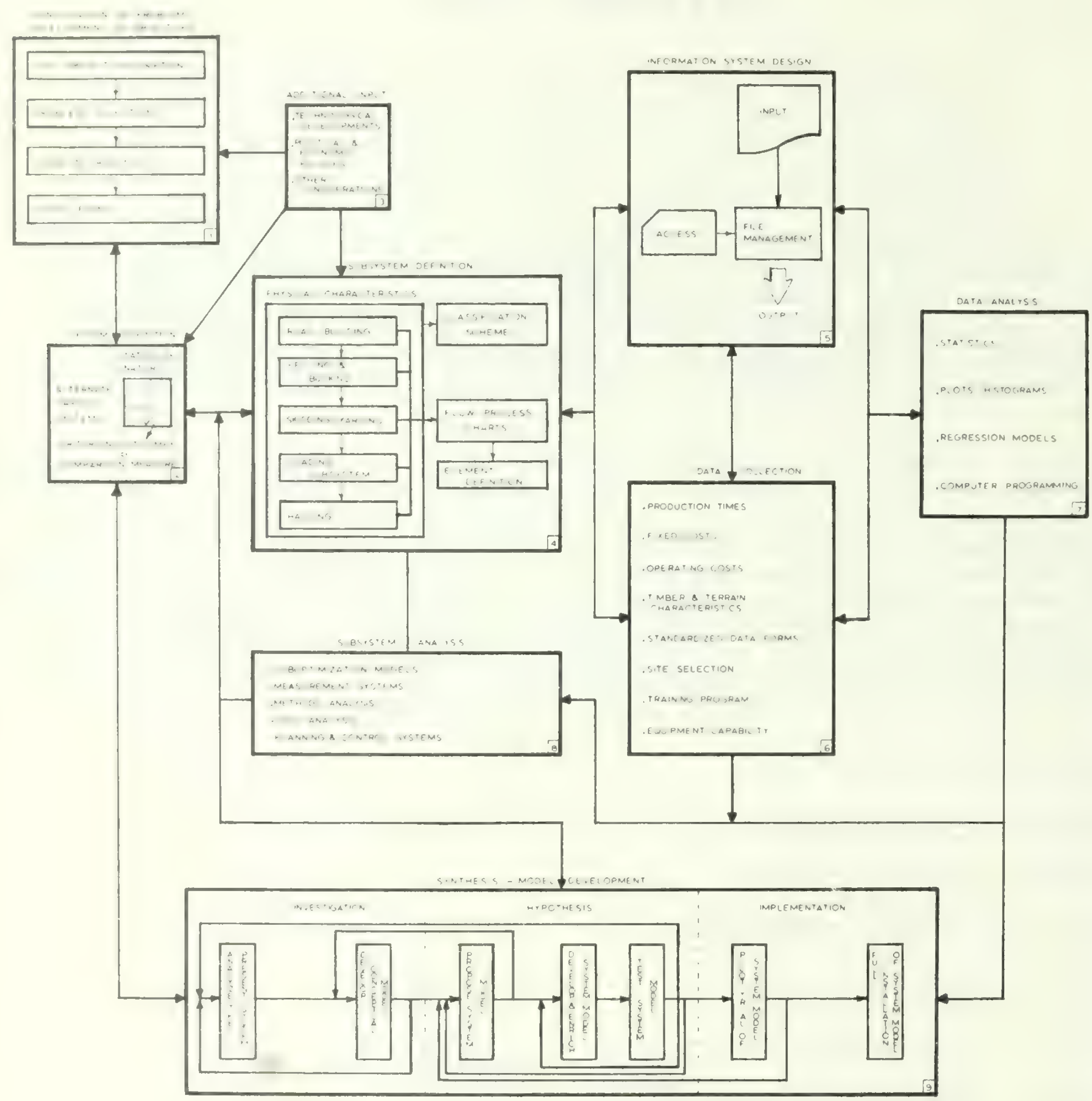


Figure 1.--Logging systems analysis.

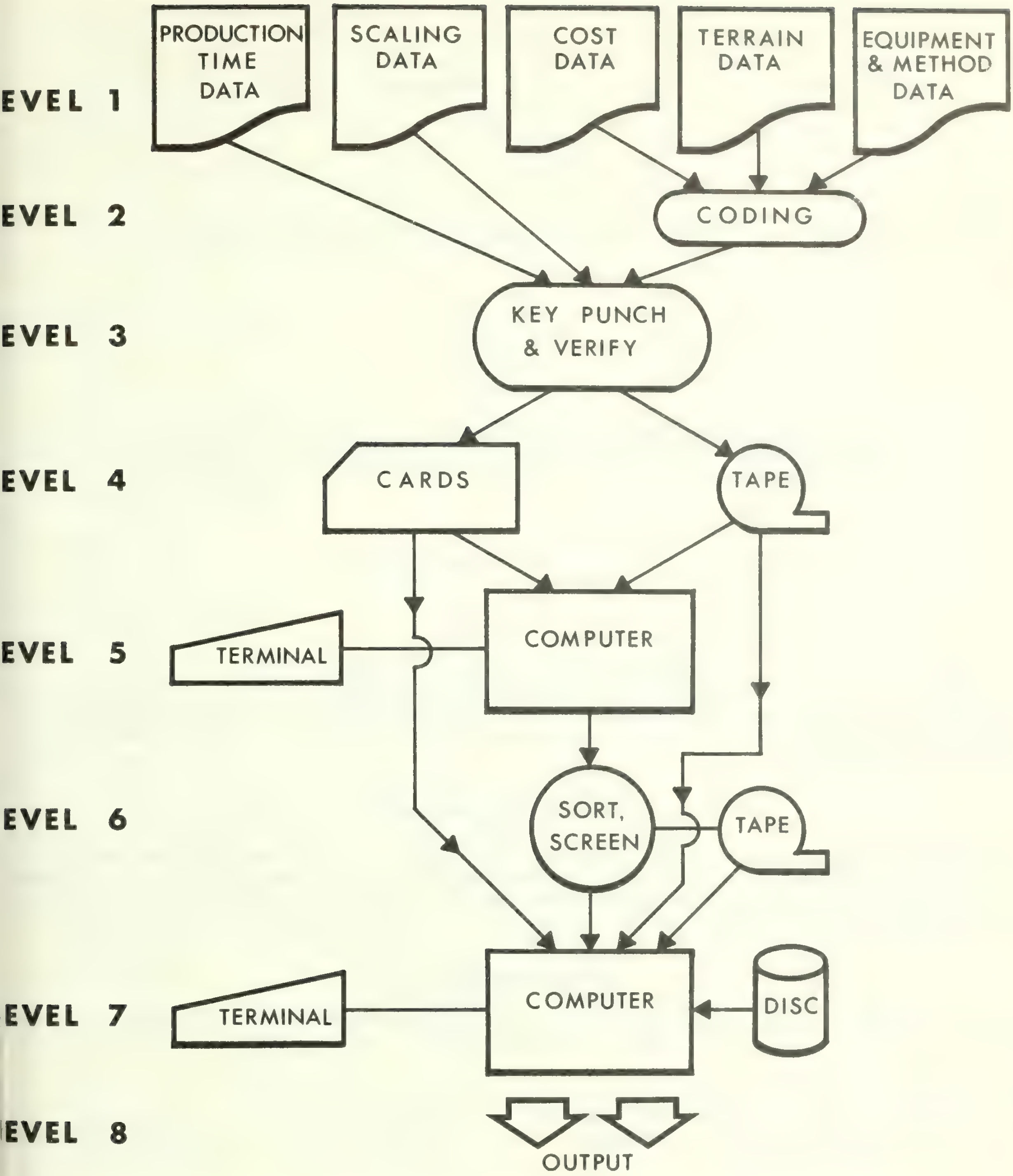


Figure 2.--Information storage and retrieval system.

SITE-TERRAIN INFORMATION FORM

Figure 3 illustrates the Site-Terrain Information Form, which is designed for observing and recording data concerning site and terrain conditions of any logging subsystem. Entries fall under three headings: site description, site conditions, and subsystem information.

Site Description

Enter three-digit code number adjacent to the subsystem (logmaking, skidding, etc.) being observed. Each code number is unique for a given location and date. Codes may be generated by starting with any three-digit number and incrementing by one each time a new code number is required.

Site Conditions

Site conditions are rated according to a numerical rating system. Check or circle the appropriate rating number on the information form, as defined below.

Surface Type

Surface type is rated on the degree to which surface obstructions hamper activity.

Ratings:

1. Little slash, downtimber, stumps, brush, or rocks; little or no detouring or maneuvering of men or equipment necessary.

2. Some slash, downtimber, stumps, brush or rocks; moderate detouring or maneuvering of men or equipment necessary.

3. Heavy slash, downtimber, stumps, brush, or rocks; excessive detouring or maneuvering of men or equipment necessary.

SITE/TERRAIN INFORMATION FORM

SITE DESCRIPTION

Logmaking ____________ Location
Skidding ____________ Timber Sale ____________
Yarding ____________ Forest ____________
Loading ____________ Type of Cut ____________
Hauling ____________ Contractor ____________
Data Collection Date ____________ Start Time ________ Stop Time ________

Comments ____________

SITE CONDITIONS

	Rating				
Surface Type	1	2	3		Comments ____________
Surface Condition	1	2	3		Comments ____________
Operator	1	2	3		Comments ____________
Landing	1	2	3	4	Comments ____________
Deck	1	2	3	4	Comments ____________

Temperature ________ degrees Elevation ________
Wind _____ velocity _____ direction Precipitation _____ amount ________ form

SUBSYSTEM INFORMATION

Logmaking Comments ____________
Crew Members
____________, Comments ____________
____________, Comments ____________
Saw or Feller
Make ________ Type ________ Equipment Owner ____________
Model ________ Size ________ Payment (Method & Amount) ____________

Skidding/Yarding Comments ____________
Crew Members
____________, Comments ____________
____________, Comments ____________
____________, Comments ____________
Skidder or Yarder
Make ________ Type ________ Equipment Owner ____________
Model ________ Size ________ Payment (Method & Amount) ____________

Loading Comments ____________
Crew Members
____________, Comments ____________
____________, Comments ____________
Loader
Make ________ Type ________ Equipment Owner ____________
Model ________ Size ________ Payment (Method & Amount) ____________

Hauling Comments ____________
Crew Members
____________, Comments ____________
____________, Comments ____________
Truck and Trailer
Make ________ Type ________ Equipment Owner ____________
Model ________ Size ________ Payment (Method & Amount) ____________

Figure 3.--Site-Terrain Information Form.

Surface Condition

Surface condition is rated on the degree to which existing surface conditions hamper activity.

Ratings:

1. Soil dry, firm; little or no loss of traction to men or equipment.

2. Soil slightly wet, soft; moderate loss of traction to men or equipment.

3. Soil very wet and muddy, loose; excessive loss of traction to men or equipment

Operator

Operators are rated on the basis of observed performance. In a one-man operation, obviously there is only one operator to be rated. In a crew operation, such as a skyline yarding system, the crew performance must be rated collectively. The term "performance" is a combined measurement of motivation, skill, and experience.

Ratings:

1. Above-average performance.

2. Average performance.

3. Below-average performance.

Landing

Landings are rated by estimating the degree to which skidding, yarding, or loading subsystems are affected by landing area characteristics.

Ratings:

1. Spacious landing area. Neither decking nor loading is hampered by any feature of the landing.

2. Adequate landing area. Either decking, loading, or both, are occasionally hampered to a moderate degree by a small or poorly arranged landing.

3. Limited landing area. Either decking, loading, or both, are continually hampered to a high degree by a small or poorly arranged landing.

4. Not applicable to these observations. (For example, landing rating would not be applicable to logmaking subsystem.)

Deck

Decks are rated on the effect that the deck arrangement and structure have on decking and loading.

Ratings:

1. Deck has all logs even at the end and parallel to each other. Greater care and time would be required to construct a deck of this type. Such a deck permits the loader to operate with maximum speed in picking and sorting logs.

2. Deck has some uneven log ends and not all logs are parallel. Generally, less time would be consumed in decking, but the loading operation would be slowed somewhat.

3. Deck has practically no log ends even and the logs are jackstrawed. Such a deck is generally the easiest to construct, but the most difficult and time-consuming from which to load.

4. Not applicable to these observations. (For example, deck classification would not be applicable to logmaking subsystem.)

Temperature

Record noon-hour temperature in degrees.

Wind

Record wind velocity and direction.

Precipitation

Record precipitation amount and form.

Elevation

Record site elevation as given on available area maps.

Subsystem Information

Record information as indicated for the subsystem being observed.

Example

To illustrate use of the Site-Terrain Information Form, consider figure 4. A mechanized felling operation was to be studied on the Targhee National Forest in northeastern Idaho. The equipment employed was a Beloit Harvester, which can fell, limb, top, and bunch trees. Information relating to site description, site conditions, and subsystem information is documented on the form as shown.

SITE/TERRAIN INFORMATION FORM

SITE DESCRIPTION

Logmaking 197
Skidding ______
Yarding ______
Loading ______
Hauling ______

Location
Timber Sale Clear Creek, Unit #3
Forest Targhee National Forest
Type of Cut Selective
Contractor Idaho Mills, Inc.

Data Collection Date 5/9/74 Start Time 7:30 a.m. Stop Time 3:30 p.m.

Comments Beloit broken down previous two days

SITE CONDITIONS

	Rating				
Surface Type	1	2	3		Comments
Surface Condition	1	2	3		Comments
Operator	1	2	3		Comments Operator 3 weeks on job
Landing	1	2	3	4	Comments
Deck	1	2	3	4	Comments

Temperature 68 degrees Elevation 3400 ft
Wind 0 velocity 0 direction Precipitation 0 amount ______ form

SUBSYSTEM INFORMATION

Logmaking Comments Trees marked for felling
Crew Members
B. Wiley, Operator, Comments 3 wks on job, trained @ Beloit Hdq.
______, Comments

Saw or Feller
Make Beloit Type ______ Equipment Owner Idaho Mills
Model 14 Size ______ Payment (Method & Amount) $.5/MBF straight

Skidding/Yarding Comments
Crew Members
______, Comments
______, Comments
______, Comments

Skidder or Yarder
Make ______ Type ______ Equipment Owner
Model ______ Size ______ Payment (Method & Amount)

Loading Comments
Crew Members
______, Comments
______, Comments

Loader
Make ______ Type ______ Equipment Owner
Model ______ Size ______ Payment (Method & Amount)

Hauling Comments
Crew Members
______, Comments
______, Comments

Truck and Trailer
Make ______ Type ______ Equipment Owner
Model ______ Size ______ Payment (Method & Amount)

Figure 4.--Completed Site-Terrain Information Form--felling.

MECHANIZED FELLING DATA FORM

Flow Process Chart

Consider figure 5, which presents a flow process chart of a mechanized felling and logmaking operation. A flow-process chart graphically defines the sequential order of elements that comprise one cycle of a particular operation. Understanding the flow process chart is essential if the observer is to accurately time and analyze an operation. In the case of mechanized felling, five elements have been defined as constituting one cycle of the operation. These five elements were defined to facilitate analysis of the effect of various independent variables on the operation. Beginning and ending points of each element are defined to indicate the precise interval of time that is to be recorded for each element.

Figure 6 illustrates a typical mechanized felling operation. The analyst gathering time study data must stay close to the equipment. He must constantly move with the equipment in order to record the element times, while simultaneously keeping a safe distance from the operation.

FLOW PROCESS CHART

SUBJECT CHARTED LOGS BY

SUBSYSTEM MECHANIZED LOGMAKING

METHOD USED SHEAR OR FELLER WITH LIMBER AND BUNCHER

CHART SYMBOL	ELEMENT DESCRIPTION	ELEMENT BEGINNING & END POINTS
0	Logs Located as Trees in Woods	
1	Equipment Travels to Next Position	Buncher Releases Tree on Ground. Tracks (or Wheels) Stationary.
2	Angular and Extensional Positioning of Vertical Mast	Tracks (or Wheels) Stationary. Vertical Mast in Position and Stationary at Tree.
3	Limbing Apparatus Limbs and Tops Tree	Vertical Mast in Position and Stationary at Tree. Limbing Apparatus Stationary.
4	Butt Shear Severs Tree	Limbing Apparatus Stationary. Tree Severed.
5	Tree Length Placed on Ground	Tree Severed. Buncher Releases Tree on Ground.
6	Logs Located as Tree Lengths on Ground	

Figure 5.--Flow process chart--mechanized felling.

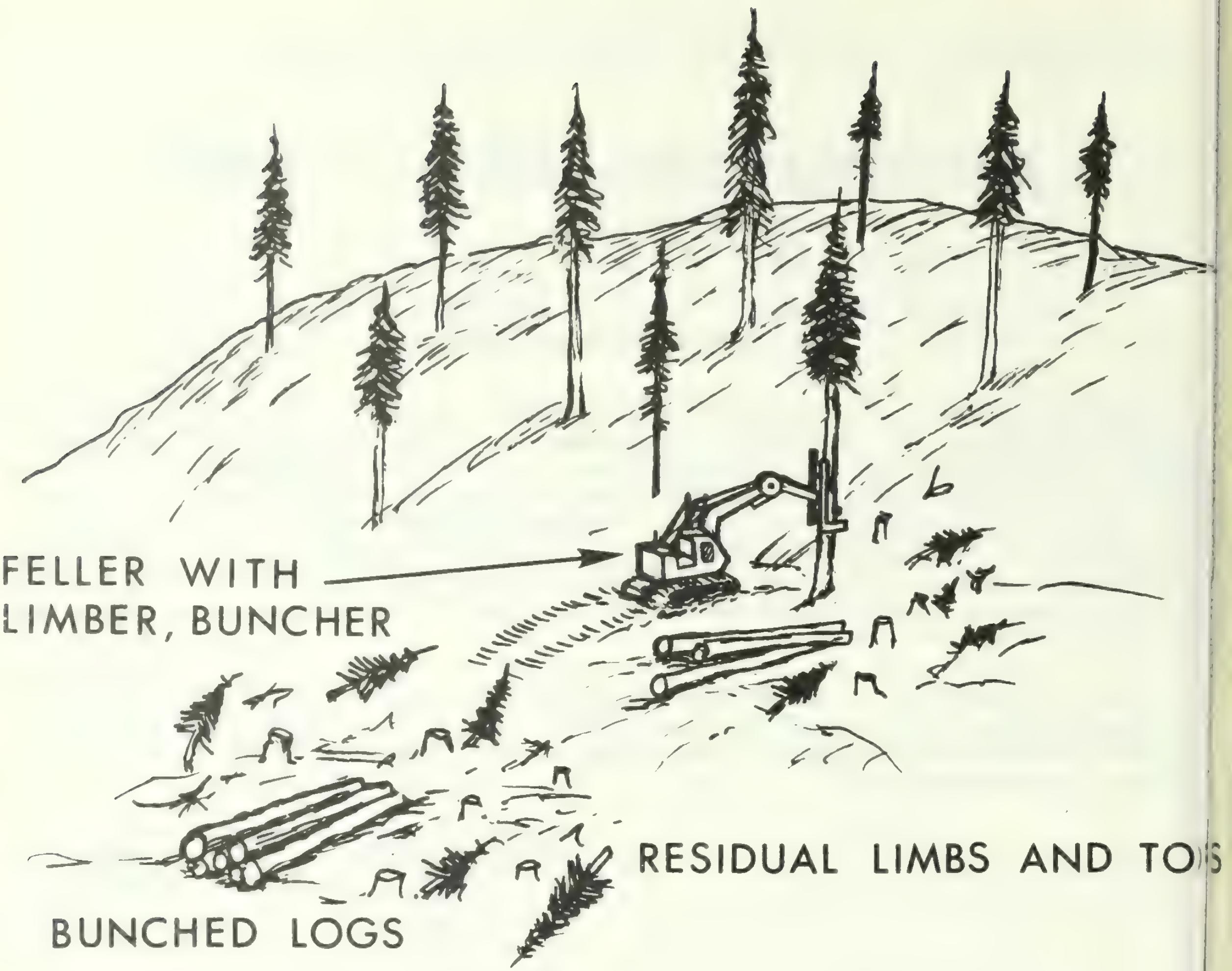


Figure 6.--Mechanized felling operation.

Form Entries

Figure 7 presents a copy of the Mechanized Felling Data Form. The form is desi ed with 80 columns for entries. Thus, data can be keypunched directly from completed f ms. This eliminates the need to transcribe data from observation forms to keypunching fo s. A detailed explanation of entries appears later. Two documents are referenced for u in relation to the form: the Site-Terrain Information Form that has already been pr sented, and the code sheet. A comprehensive coding system for entries such as equip ment, method, and foreign elements will be published as an appendix to this document

MECHANIZED LOGMAKING DATA-CYCLE ELEMENT TIME STUDY FORM
Snapback Reading

SUBSYSTEM	EQUIPMENT & METHOD	CODE NO.	1 TRA-VEL	2 POSI-TION	3 LIMB & TOP	4 FELL	5 BUNCH	FOREIGN ELEMENT	DIST. (FT)	SLOPE (%)	SWING (S)	DIA. TOP (IN)	DIA BUTT (IN)	LENGTH (FT)	SPECIES	MVR MBF/A	TREES PER ACRE (TENS)	TCV (CUNIT)	SURFACE T	SURFACE C	OPERATOR	I D	ADDITIONAL DATA	CONTINUE
1	2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24 25 26 27 28 29	30 31 32	33 34 35	36 37 38	39 40	41 42	43 44	45	46 47	48 49 50	51 52	53	54	55	56	57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79	80

Figure 7.--Mechanized Felling Data Form.

Entries made in columns 1-6 (inclusive) and 45-55 (inclusive) will most likely be repeated for a considerable number of turns. Thus, it is necessary only to make one entry at the beginning of each time-study sheet; new entries are required only when information in these columns changes.

Column	*Entry*	*Explanation*
1	Subsystem	One-digit entry identifies subsystem; per code sheet.
2-3	Equipment and Method	Two-digit entry identifies method used to accomplish subsystem function and also brand name and model used (per code sheet).
4-6	Code Number	Three-digit entry to identify observations and that matches with code number on Site-Terrain Information Form.
7-9	Travel	Enter three digits representing time taken to perform element as defined on Flow Process Chart. Enter time to nearest one-hundredth of a minute. Enter decimal portion to right of dashed line; enter whole number portion to left of dashed line.

Column	*Entry*	*Explanation*
10-12	Position	See explanation for col. 7-9.
13-15	Limb and Top	See explanation for col. 7-9.
16-18	Fell	See explanation for col. 7-9.
19-21	Bunch	See explanation for col. 7-9.
22-29	Foreign Element	As a group, the columns present information on foreign elements that occur. A foreign element is defined as an element that does not occur regularly on each cycle. Enter single digit in col. 22 to identify foreign element type (per code sheet). Enter a single digit in col. 23 to identify regular element in which a foreign element occurred (see numbers above regular elements on Data Form). Enter up to three digits in col. 24-26 representing time elapsed in the regular element (entered in col. 23) when the foreign element began. Record time to the nearest tenth of a minute. Follow procedure for entering times described in col. 7-9 explanation. Enter up to three digits in col. 27-29 representing time duration of foreign element. Record time to the nearest tenth of a minute.
30-32	Distance	Enter maximum of four digits representing distance the equipment travels from one tree to another. In other words, the distance covered during the travel element, when the equipment location changes. A zero distance is entered when only positioning is necessary, and equipment location is unchanged.
33-35	Slope	Enter maximum of three digits representing slope between two successive trees that are harvested. If the equipment travels uphill, slope is positive; downhill travel, slope is negative. No slope is entered when only the positioning arm moves from one tree to another.
36-38	Swing	Enter maximum of three digits representing degrees in the arc that is described by movement during the Bunch element. In other words, the angle that the tree length is transferred from the stump to the bunch on the ground.
39-40	Diameter Top	Enter maximum of two digits representing top diameter of tree length if tree is topped, or minimum merchantable diameter if tree is not topped.
41-42	Diameter Butt	Enter maximum of two digits representing stump diameter.

Column	*Entry*	*Explanation*
43-44	Length	Enter maximum of two digits representing finished tree length if tree is topped, or merchantable length if tree is not topped.
45	Species	Enter single digit (per code sheet) representing species of tree processed during current cycle.
46-47	Merchantable Volume Removed (MVR)	Enter maximum of two digits representing merchantable volume of timber (expressed in thousand board feet per acre) being removed from sale unit observed.
48-50	Trees Per Acre	Enter maximum of three digits representing the total number of trees (expressed in tens and including trees harvested and unharvested) located on the sale unit observed.
51-52	Total Cubic Volume (TCV)	Enter maximum of two digits representing volume, expressed in hundreds of cubic feet (CUNIT), of timber located on sale unit.
53	Surface Type	Enter one digit classifying the surface type as outlined on the Site-Terrain Information Form.
54	Surface	Enter one digit classifying the surface condition as outlined on the Site-Terrain Information Form.
55	Operator(s)	Enter a one-digit rating of operator(s) performance as outlined on the Site-Terrain Information Form.
56-79	Additional Data	Available for additional data. Entries explained in next section.
80	Continue	An entry in the continuation column indicates that data pertaining to the current line of entry are continued to the next line in the data-gathering form. Any numeric digit, other than zero, may be entered in the continuation column. The continuation line will contain data only in the additional data field.

Explanation of Entries in Additional Data Columns on Mechanized Logmaking Data Form

Explanation of Entries in Additional Data Columns on Mechanized Logmaking Data Form

Additional data columns are used to record data pertaining to an observation when the prescribed columns of entry are not sufficient.

Column	*Entry*	*Explanation*
56	Identification (I.D.)	Enter one digit (per code sheet) to identify reason that continuation was necessary.
57-65	Foreign Element	When I.D. = 1, enter the second foreign element for that observation according to previous foreign element instructions. Other data pertaining to additions are entered according to defined conventions (i.e., the entry made in columns 57-XX will depend upon the I.D. entry in col. 56.)

More than one foreign element (or other type of data) can be given in columns 57-79. Once the I.D. number is read, the computer is keyed to the number of columns to be read. After reading data related to the first I.D. number, the computer checks the next column for another I.D. number. For example, columns 57-79 have the capacity to accommodate data related to two foreign elements. Further, if columns 57-79 are used to capacity, additional data can be accommodated in the additional data columns of the next line. In such a case, a numeric entry is made in column 80.

Mechanized Logmaking Data Example

Consider figure 8, which shows the Mechanized Felling Data Form with sample entrie Two cycles of mechanized felling are covered in order to illustrate the use of all columns. Subsystem, Equipment and Method, and Code No. entries are written in columns 1 through 6. These entries need not be made for each line, but should be made whenever a change occurs.

Upon releasing a log on the ground, a Beloit Harvester travels 10 feet to another position in 0.10 minute. The slope of travel is 10 percent uphill. When travel is completed, positioning of the vertical mast requires 0.18 minute. The tree is limbed and topped in 0.30 minute. The shear fells the tree in 0.10 minute. The bunching element requires 0.29 minute, and the tree length is moved through an angle of 45°.

No travel is required to the next tree to be cut, thus no entry is required under Travel. Positioning requires 0.20 minute. Upon completion of positioning, the operator leaves the machine running and dismounts, consuming 2.0 minutes for personal delay a type 4 foreign element. Upon remounting harvester, the tree is limbed and topped in 0.20 minute, and felling requires 0.05 minute. The tree is bunched in 0.35 minute, while being transported through a 45° angle.

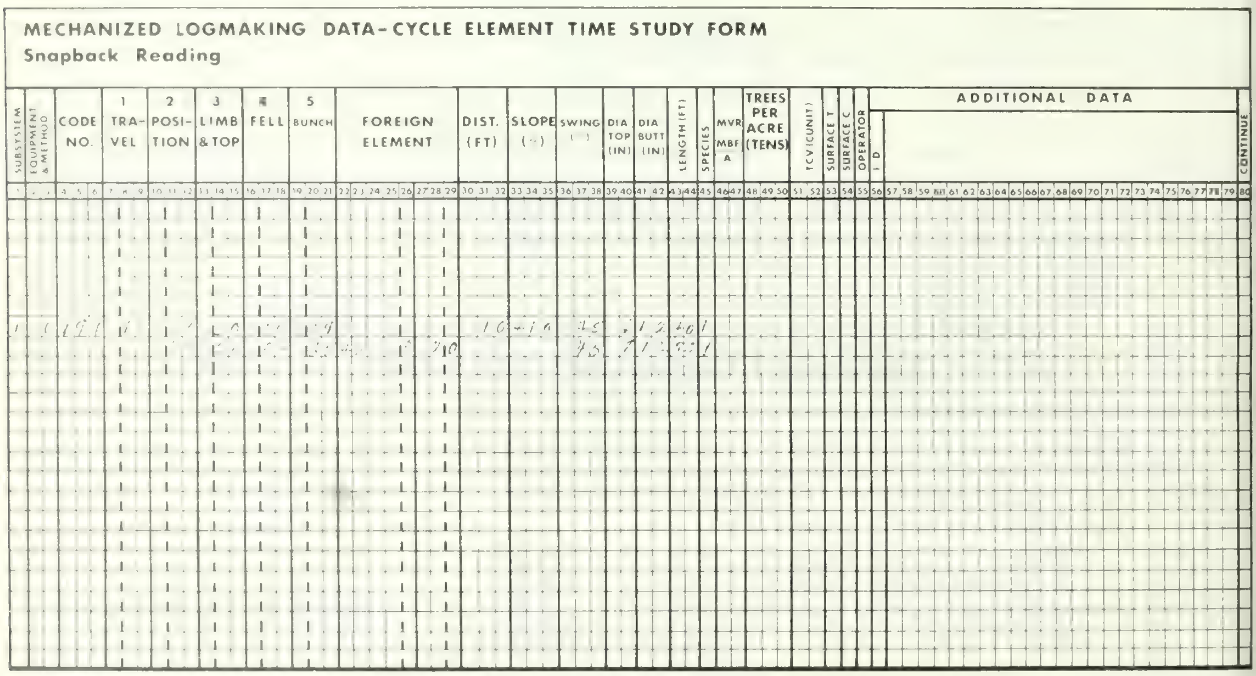


Figure 8.--Mechanized Felling Data Form with sample entries.

SKIDDING DATA FORM

On the timber sale used to develop this handbook, skidding was done by means of a rubber-tired skidder equipped with a grapple--John Deere Model JD 540-A Skidder equipped with a John Deere Model 3605 Grapple.

It was desired to analyze the skidding subsystem to determine effects of independent variables on skidding cycle time. As in the felling subsystem, initial conditions were documented using the Site-Terrain Information Form. It should be noted that a different copy (as opposed to using the one completed for the felling operation) of the form was used because data such as site conditions, observation day, observer, and other information may have changed. Also, note that a separate form would be completed for each skidder observed. Figure 9 shows a copy of the completed form.

SITE/TERRAIN INFORMATION FORM

SITE DESCRIPTION

Logmaking ______ Location
Skidding 2.35 Timber Sale Clear Creek, Unit #3
Yarding ______ Forest Targhee National Forest
Loading ______ Type of Cut Selective
Hauling ______ Contractor Idaho Mills, Inc.
Data Collection Date 6/12/74 Start Time 8:30 a.m. Stop Time 3:30 p.m.
Comments ______

SITE CONDITIONS

	Rating				
Surface Type	1	(2)	3		Comments
Surface Condition	(1)	2	3		Comments
Operator	1	(2)	3		Comments
Landing	(1)	2	3	4	Comments
Deck	(1)	2	3	4	Comments Small decks, simultaneous loading

Temperature 78 degrees Elevation 3400 feet
Wind 0 velocity — direction Precipitation ______ amount ______ form

SUBSYSTEM INFORMATION

Logmaking Comments ______
Crew Members
______, Comments ______
______, Comments ______
Saw or Feller
Make ______ Type ______ Equipment Owner ______
Model ______ Size ______ Payment (Method & Amount) ______

Skidding/Yarding Comments ______
Crew Members
Bob Martin, Comments Average Operator (according to contractor)
______, Comments ______
______, Comments ______
Skidder or Yarder
Make John Deere Type ______ Equipment Owner Gyppo - Martin
Model JD 540-A Size ______ Payment (Method & Amount) $.25/log

Loading Comments ______
Crew Members
______, Comments ______
______, Comments ______
Loader
Make ______ Type ______ Equipment Owner ______
Model ______ Size ______ Payment (Method & Amount) ______

Hauling Comments ______
Crew Members
______, Comments ______
______, Comments ______
Truck and Trailer
Make ______ Type ______ Equipment Owner ______
Model ______ Size ______ Payment (Method & Amount) ______

Figure 9.--Completed Site-Terrain Information Form--skidding.

Flow Process Chart

Once the time-study observer has gained familiarity with rubber-tired skidder operations, he can examine the flow process chart. The time-study form developed for skidding can be used for both choker and grapple operations. Consider figure 10 which is the flow process chart for skidding with chokers. Eight elements are involved in skidding with chokers. Elements 2, 3, and 4 may be repeated in a cycle if the skidder must travel to more than one location for logs. Figure 11 shows the flow process chart for skidding with a grapple. Note that this is basically the same as the flow chart presented in figure 10 except that elements 3 and 6 have been eliminated.

FLOW PROCESS CHART

SUBJECT CHARTED [illegible] BY

SUBSYSTEM [illegible]

METHOD USED [illegible]

CHART SYMBOL	ELEMENT DESCRIPTION	ELEMENT BEGINNING & END POINTS
0	Logs Located in Woods	
1	Skidder Travels Unloaded from Deck to Logs in Woods	Skidder starts moving toward woods Operator dismounts skidder, or setter starts to hook chokers
2	Choker(s) Hooked to Log(s)	Operator dismounts skidder, or setter starts to hook chokers Operator remounts skidder, or setter completes setting last ch
3	Logs Winched Free	Operator remounts skidder, or setter completes setting last ch Skidder starts movement
* 4	Skidder Travels Partially Loaded to Next Location for Log Pick Up	Skidder starts movement Operator dismounts skidder, or setter starts to hook chokers
* 2	Choker(s) Hooked to Log(s) and to Winch Mainline	Operator dismounts skidder, or setter starts to hook chokers Operator remounts skidder, or setter completes setting last ch
* 3	Logs Winched Free	Operator remounts skidder, or setter completes setting last ch. Skidder starts movement
5	Skidder Travels Loaded from Woods to Deck	Skidder starts movement Operator dismounts skidder, or deckman begins to unhook ch.
6	Choker(s) Unhooked from Log(s)	Operator dismounts skidder, or deckman begins to unhook ch. Operator remounts skidder, or deckman finishes unhooking ch.
7	Skidder Decks Log(s) at Landing	Operator remounts skidder, or deckman finishes unhooking ch. Skidder starts moving toward woods
8	Logs Located at Landing	
* NOTE	These elements may be repeated and will exist when several stops are made to pick up logs.	

Figure 10.--Flow process chart--skidding with chokers.

igure 11.--Flow rocess chart-- kidding with grapple.

FLOW PROCESS CHART

SUBJECT CHARTED LOGS BY

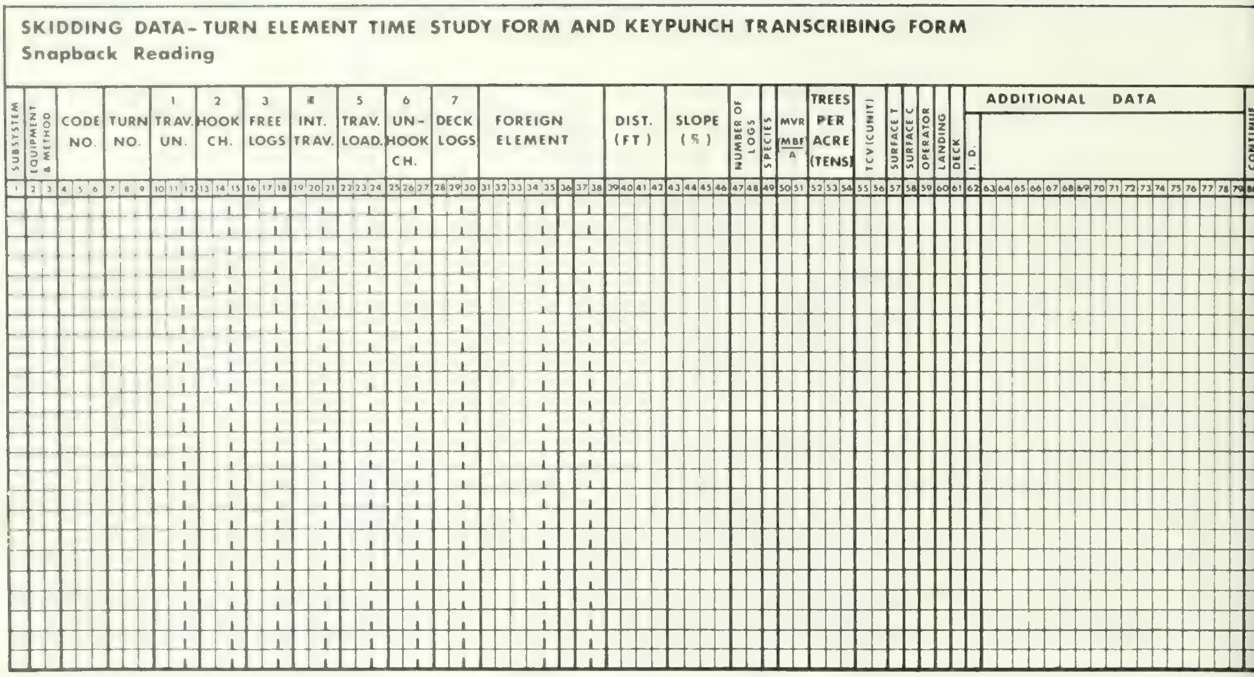
SUBSYSTEM SKIDDING

METHOD USED GRAPPLE

CHART SYMBOL	ELEMENT DESCRIPTION	ELEMENT BEGINNING & END POINTS
0	Logs Located in Woods	
1	Skidder Travels Unloaded from Deck to Logs in Woods	Skidder starts moving toward woods Grapple begins movement to pick up log(s).
2	Grapple Loaded (May be concurrent with skidder back in movement)	Grapple begins movement to pick up log(s). Skidder starts forward movement
* 4	Skidder Travels Partially Loaded to Next Location for Log Pick Up	Skidder starts forward movement Grapple drops partial load
* 2	Grapple Reloaded	Grapple drops partial load Skidder starts forward movement
5	Skidder Travels Loaded from Woods to Deck	Skidder starts forward movement Grapple drops log load at deck
7	Skidder Decks Log(s) at Landing	Grapple drops log load at deck Skidder starts moving toward woods
8	Logs Located at Landing	
* NOTE:	These elements may be repeated and will exist when several stops are made to pick up logs. Elements are numbered to correspond to columns on Skidding Data Form.	

Form Entries

Figure 12 presents a copy of the Skidding Data Form. The form is constructed from a standard 80-column computer coding sheet. Entries can therefore be directly transcribed to cards via keypunching.


SKIDDING DATA- TURN ELEMENT TIME STUDY FORM AND KEYPUNCH TRANSCRIBING FORM
Snapback Reading

SUBSYSTEM	EQUIPMENT & METHOD	CODE NO.	TURN NO.	1 TRAV. UN.	2 HOOK CH.	3 FREE LOGS	4 INT. TRAV.	5 TRAV. LOAD.	6 UN-HOOK CH.	7 DECK LOGS	FOREIGN ELEMENT	DIST. (FT)	SLOPE (%)	NUMBER OF LOGS	SPECIES	MVR MBF/A	TREES PER ACRE (TENS)	TCV (CUNIT)	SURFACE T	SURFACE C	OPERATOR	LANDING DECK	I. D.	ADDITIONAL DATA	CONTINUE
1	2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24	25 26 27	28 29 30	31 32 33 34 35 36 37 38	39 40 41 42	43 44 45 46	47 48	49	50 51	52 53 54	55 56	57	58	59	60 61	62	63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79	80

Figure 12.--Skidding Data Form.

An explanation of entries on the form follows. A turn or cycle consists of a number of elements as defined on the flow process chart. When some of the elements are repeated within a turn, data are entered on the mainline (first line of the turn) and on sublines (lines following the mainline). Generally speaking, the mainline contains data applicable to the whole turn, and the sublines contain data pertaining to repeated elements of the turn. In cases where one line of entries is all that is required, the terminology "last subline" would refer to the mainline. When timing a skidder with a grapple, column 16-18 and 25-27 are not used, and column 13-15 are used for loading the grapple.

Column	*Entry*	*Explanation*
1	Subsystem (Mainline)	One-digit entry identifies subsystem; per code sheet.
2-3	Equipment & Method (Mainline)	Two-digit entry identifies method used to accomplish subsystem function and also brand name and model used; per code sheet.

Column	*Entry*	*Explanation*
4-6	Code Number (Mainline)	Three-digit entry to identify observations and that matches code number on Site-Terrain Information Form. It is important that a code number be unique to a particular study location and date.
7-9	Turn (Mainline)	Three-digit entry identifying the turn being observed. (Number turns consecutively for any given code number.)
10-12	Travel Unloaded (Mainline)	Enter three digits representing time taken to perform element as defined on flow process chart. Enter time to nearest tenth of a minute. Enter decimal portion to right of dashed line; enter whole number portion to left of dashed line.
13-15	Hook Chokers (Mainline)	See explanation for col. 10-12. Enter on mainline time for hooking logs at first location the skidder stops.
13-15	Hook Chokers (Subline)	See explanation for col. 10-12. Enter on sub-line time for hooking log(s) at successive locations of the turn.
16-18	Free Logs (Mainline)	See explanation for col. 10-12. Enter on mainline time for freeing log(s) at first location of the turn.
16-18	Free Logs (Subline)	See explanation for col. 10-12. Enter on subline time for freeing log(s) at successive locations of the turn.
19-21	Intermediate Travel (Mainline)	No entry; drop to first subline when this element first occurs.
19-21	Intermediate Travel (Subline)	See explanation for col. 10-12. Enter on first subline time for first intermediate travel of the turn. Enter on successive sublines intermediate travel times.
22-24	Travel Loaded (Last Subline)	See explanation for col. 10-12. Following the subline where entry was made for the last repeated element, enter time for travel loaded. This entry is on the last subline.
25-27	Unhook Chokers (Last Subline)	See explanation for col. 10-12. Enter on last subline time for unhooking chokers. Enter on mainline if there are no sublines.
28-30	Deck Logs (Last Subline)	See explanation for col. 10-12. On last subline enter time for decking logs. Mainline is used if there are no sublines.

Column	Entry	Explanation
31-38	Foreign Element (Mainline & Subline)	As a group, the columns present information on foreign elements that occur. A foreign element is an element that does not occur regularly on each turn. Enter single digit in col. 31 to identify foreign element (per code sheet). Enter a single digit in col. 32 to identify regular element in which a foreign element occurred (see numbers above regular elements on Data Form). Enter three digits in col. 33-35 representing time elapsed in the regular element (entered in col. 32) when the foreign element began. Follow procedure for entering times described in col. 10-12 explanation.
39-42	Distance (Mainline)	Enter three digits in col. 36-38 representing time duration of foreign element. Record time to nearest tenth of a minute. Enter maximum of four digits representing distance traveled from deck to location where first log(s) are hooked. In other words, enter distance covered during travel unloaded element.
39-42	Distance (Subline)	Enter distance covered by first intermediate travel on first subline. On successive subline enter subsequent intermediate travel distances.
39-42	Distance (Last Subline)	Enter distance traveled from location where last log(s) are hooked to deck. In other words, enter distance covered during travel loaded element.
43-46	Slope (Mainline)	Enter slope (percent) from deck to general log location. Assuming the observer to be at deck, enter a positive slope when logs are skidded uphill toward deck, a negative slope when logs are skidded downhill toward deck.
47-48	Number of Logs (Mainline & Subline)	Enter the number of logs hooked on the same line used to record Hook Ch. (hook chokers) time.
49	Species (Mainline & Subline)	Enter digit (per code sheet) representing species of logs hooked on the same line used to record Hook Ch. time.
50-51	Merchantable Volume Removed (MVR) (Mainline)	Enter maximum of two digits representing merchantable volume of timber (expressed in thousand board feet per acre) being removed from sale unit.
52-54	Trees Per Acre (Mainline)	Enter maximum of three digits representing the total number of trees (expressed in tens and including trees harvested and unharvested) located on the sale unit observed.

olumn	*Entry*	*Explanation*
55-56	Total Cubic Volume (Mainline)	Enter maximum of two digits representing cubic foot volume expressed in hundred of cubic feet (CUNIT), of timber located on sale unit.
57	Surface Type (Mainline)	Enter one digit classifying the surface type as outlined on the Site-Terrain Information Form.
58	Surface Condition (Mainline)	Enter one digit classifying the surface condition as outlined on the Site-Terrain Information Form.
59	Operator(s) (Mainline)	Enter a one-digit rating of operator's performance as outlined on the Site-Terrain Information Form.
60	Landing (Mainline)	Enter one digit classifying the landing area as outlined on the Site-Terrain Information Form.
61	Deck (Mainline)	Enter one digit classifying the deck as outlined on the Site-Terrain Information Form.
62-79	Additional Data	Available for additional data. Entries explained in next section.
80	Continue	An entry in the continuation column indicates that data pertaining to the current line of entry are continued to the next line on the data-gathering form. Any numeric digit, other than zero, may be entered in the continuation column. The continuation line will contain data only in the additional data field.

Explanation of Entries in Additional Data Columns

Additional data columns are used to record data that cannot be entered in the prescribed columns.

Following are additional data column entries for Skidding Data Forms:

Column	*Entry*	*Explanation*
62	Identification (I.D.)	Enter one digit (per code sheet) to identify reason that continuation was necessary.
63-70	Foreign Element	When I.D. = 1, enter the second foreign element for that line according to previous instructions.
63-XX		Other data pertaining to additions are entered according to defined conventions (i.e., the entry made in columns 63-XX will depend on the I.D. entry in col. 62.)

More than one foreign element (or other type of data) can be given in col. 63-79. Once the I.D. number is read, the computer is keyed for the number of columns to be read. After reading data related to the first I.D. number, the computer checks the next column for another I.D. number. For example, columns 63-79 have the capacity to accommodate data related to two foreign elements. Further, if columns 63-79 are used to capacity, additional data can be accommodated on the next line. In such a case, a numeric entry is made in column 80.

Choker Skidding Data Example

An example of the use of the Skidding Data Turn Element Time Study Form follows. The skidding situation is illustrated in figure 13, and form entries are illustrated in figure 14.

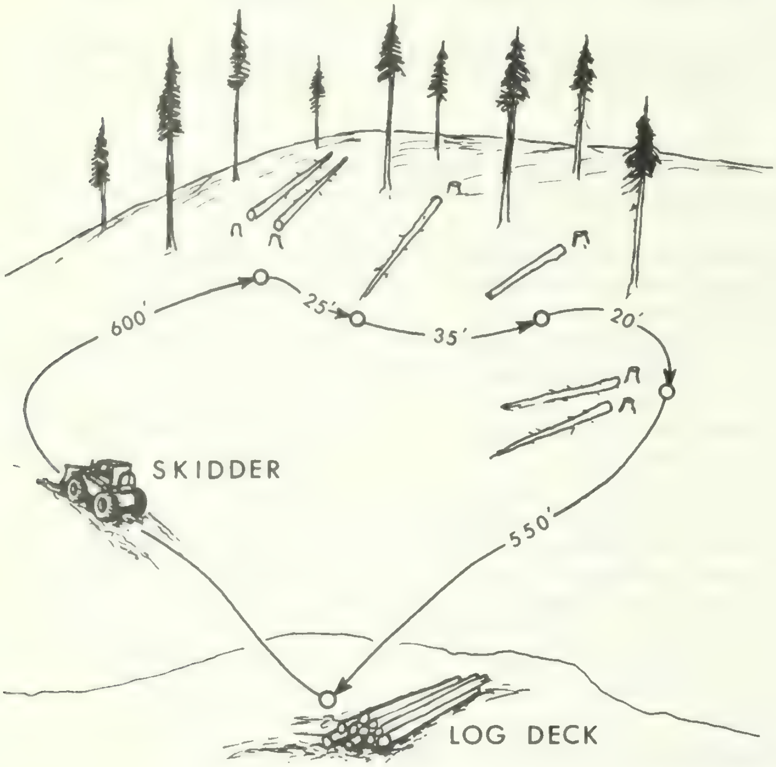


Figure 13.--Skidding operation--chokers.

SKIDDING DATA- TURN ELEMENT TIME STUDY FORM AND KEYPUNCH TRANSCRIBING FORM
Snapback Reading

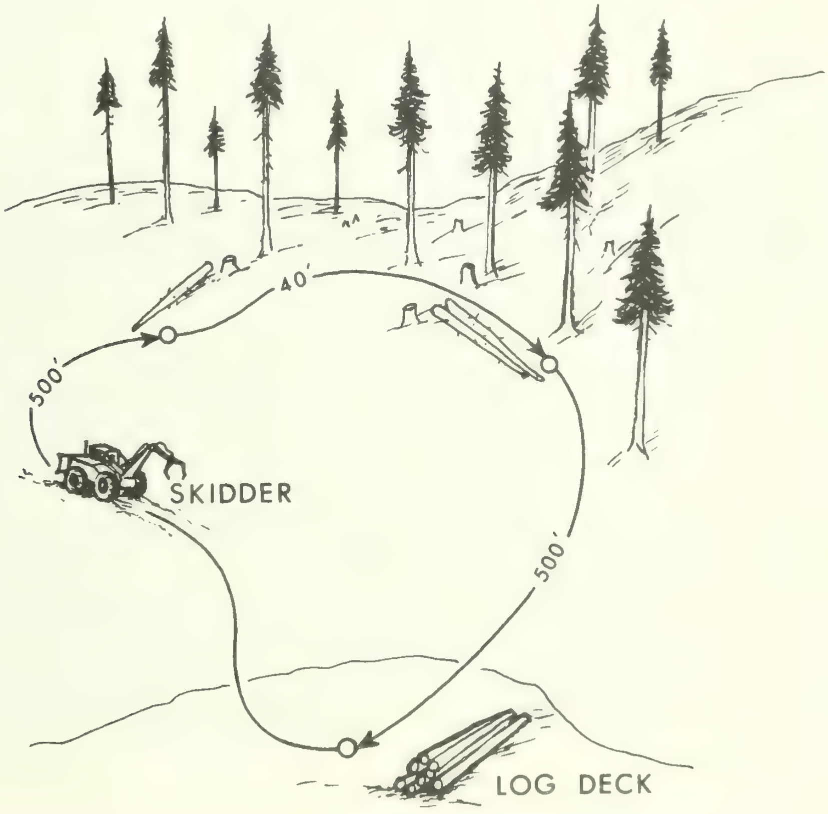
SUBSYSTEM	EQUIPMENT & METHOD	CODE NO.	TURN NO.	1 TRAV. UN.	2 HOOK CH.	3 FREE LOGS	INT. TRAV.	5 TRAV. LOAD.	6 UN-HOOK CH.	7 DECK LOGS	FOREIGN ELEMENT	DIST. (FT)	SLOPE (%)	NUMBER OF LOGS	SPECIES	MVR (MBF/A)	TREES PER ACRE (TENS)	TCV (CUNIT)	SURFACE T.	SURFACE C	OPERATOR	LANDING	DECK	ADDITIONAL DATA I. D.	ADDITIONAL DATA
1	2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24	25 26 27	28 29 30	31 32 33 34 35 36 37 38	39 40 41 42	43 44 45 46	47 48	49	50 51	52 53 54	55 56	57	58	59	60	61	62	63–79
2	10	125	17	32	7	3					32 00 17	600	-20	2	1	28	545	53	2	2	1	1	1		
					7	10	3					25		1	1										
					7	16	14					35		1	2										
					9	12	1					20		2	1										
								28	16	17	26 14 5	550													

Figure 14.--Completed Skidding Data Form--chokers.

Subsystem, Equipment and Method, and Code No. have been entered in col. 1 hrough 6. These entries need not be repeated for each line of entry, but may be made nly when a change occurs. On the 17th turn, the skidder leaves the deck and travels 00 feet in 3.2 minutes to a location where the first logs are picked up. The operator ismounts and, before he begins hooking chokers, incurs a foreign element of type 3, hich lasts 1.9 minutes. He then hooks chokers on two logs of species 1, which take .7 minute. After remounting the skidder, he winches the logs free in 0.3 minute, and ravels 25 feet to another log in 0.3 minute. Hooking this log of species 1 takes 0.7 inute. Again the operator remounts. No time is required to free logs, and he travels 5 feet in 0.4 minute for additional logs. One log of species 2 is hooked in 0.7 inute. Once again, after remounting, no winching is necessary, and he travels 20 feet n 0.1 minute to two more logs of species 1. Hooking time is 0.9 minute. Freeing logs equires 0.2 minute, then the skidder heads for the deck, traveling 550 feet in 2.8 inutes. At the deck, the operator dismounts, and begins to unhook the six logs in the oad. When 0.4 minute has elapsed, the operator incurs a type 2 foreign element which asts for 0.5 minute. He then resumes unhooking chokers, which has a net duration of .6 minute. The operator remounts the skidder and decks the log load in 0.7 minute. ol. 50 through 56 contain volume information obtained from cruise data.

Grapple Skidding Data Example

An example of the use of the Skidding Data Turn Element Time Study Form for grapple kidding follows. The example is illustrated in figure 15, and entries on the form re illustrated in figure 16. It should be noted that columns 16-18 and 25-27 are not sed, and that columns 13-15 are used for loading the grapple.



igure 15.--Skidding eration--grapple.

SKIDDING DATA- TURN ELEMENT TIME STUDY FORM AND KEYPUNCH TRANSCRIBING FORM
Snapback Reading

SUBSYSTEM	EQUIPMENT & METHOD	CODE NO.	TURN NO.	1 TRAV. UN.	2 HOOK CH.	3 FREE LOGS	4 INT. TRAV.	5 TRAV LOAD.	6 UN-HOOK CH.	7 DECK LOGS	FOREIGN ELEMENT		DIST. (FT)	SLOPE (%)	NUMBER OF LOGS	SPECIES	MVR MBF A	TREES PER ACRE (TENS)	TCV (CUNIT)	SURFACE T	SURFACE C	OPERATOR	LANDING	DECK	I D	ADDITIONAL DATA
1	2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24	25 26 27	28 29 30	31 32 33 34 35	36 37 38	39 40 41 42	43 44 45 46	47 48	49	50 51	52 53 54	55 56	57	58	59	60	61	62	63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78
[illegible]	[illegible]	5 [illegible]	1 [illegible]	19	9								500	-25	1	1	28	534	81	2	2	1	1	2		
					7		3				24 2	6	40		2	1										
								18		10			500													

Figure 16.--Completed Skidding Data Form--grapple.

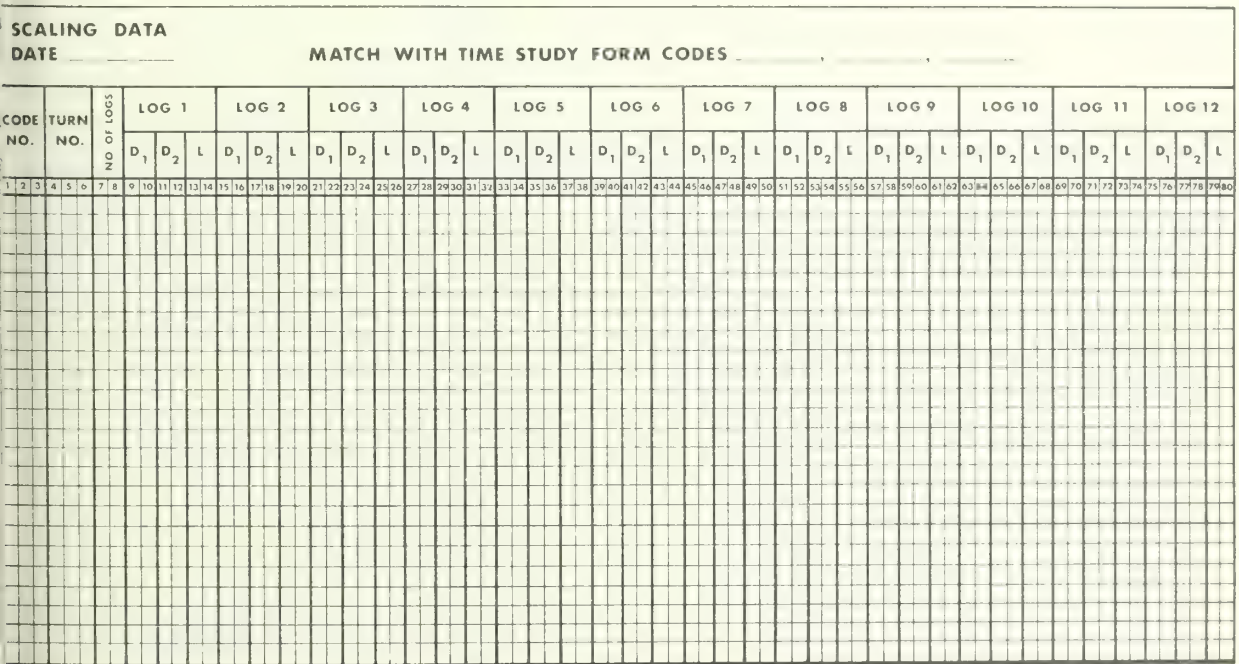
A skidder leaves the deck and travels 500 feet in 1.9 minutes to a location whe a log is to be picked up. The grapple is opened and begins descending as the skidde backs up to a log of species 1. It takes 0.9 minute to load the grapple. The skidd moves (intermediate travel) to pick up two logs of species 1 that are 40 feet away. When the skidder has moved for 0.2 minute, the log is jarred loose from the grapple and then is retrieved, which is entered as a type 2 foreign element, taking 0.6 minu Upon resuming intermediate travel, the skidder reaches the next logs in 0.1 addition minute. Straddling these two logs, the grapple drops the single log and then picks all three logs in 0.7 minute. The skidder then returns 500 feet to the deck in 1.8 minutes and deposits and decks the load in 1.0 minute. Volume entries are obtained from cruise data. Subsystem, Equipment and Method, and Code No. entries have been made in col. 1 through 6. Slope is negative because logs are skidded downhill towa the deck.

SCALING DATA FORM

The measurement of scaling information is generally an integral part of a study of logging operations. In the study of some logging subsystems such as logmaking and loading, scaling data is entered directly on the appropriate time-study form (e.g., Mechanized Felling Data Form and Loading Data Form, respectively). However, scaling data cannot be included on the time-study forms of subsystems such as skidding mainly because space on the forms is limited. Such data are recorded on the Scaling Data Form (fig. 17). This form is adapted from a standard 80-column keypunch sheet and has the capability of recording the dimensions of up to 12 logs per load or turn.

Form Entries

An explanation of entries on the Scaling Data Form follows.


SCALING DATA
DATE ___

MATCH WITH TIME STUDY FORM CODES ___, ___, ___

CODE NO.	TURN NO.	NO OF LOGS	LOG 1			LOG 2			LOG 3			LOG 4			LOG 5			LOG 6			LOG 7			LOG 8			LOG 9			LOG 10			LOG 11			LOG 12		
			D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L	D_1	D_2	L
1 2 3	4 5 6	7 8	9 10	11 12	13 14	15 16	17 18	19 20	21 22	23 24	25 26	27 28	29 30	31 32	33 34	35 36	37 38	39 40	41 42	43 44	45 46	47 48	49 50	51 52	53 54	55 56	57 58	59 60	61 62	63 64	65 66	67 68	69 70	71 72	73 74	75 76	77 78	79 80

Figure 17.--Scaling Data Form.

Column	*Entry*	*Explanation*
1-3	Code Number	Three-digit entry to identify operation being observed. Entry matches with code number on the appropriate Site-Terrain Information Form and the appropriate time-study form. This entry need only be inserted once and thereafter only when a change occurs.
4-6	Turn Number	Entry to identify the turn being observed. Turns are numbered consecutively for a given code number and correspond to the turn number on the appropriate time-study form.
7-8	Number of Logs	Enter the number of logs in the turn.
9-80 (12,6-digit fields)	Log Scale	As a group, these columns record information pertaining to log size. Data for each log will fill six columns. The data consist of small and large end diameters in inches, D1 and D2 respectively, each allotted up to 2 columns and in addition the log length, L, expressed in feet also allotted up to 2 columns.

Scaling Data Example

Figure 18 is an example of how entries are made on the Scaling Data Form. The entries correspond to the three logs skidded in the example recorded in figure 16. Here the code number was 185 and the turn number was 12. The sizes of D1, D2, and L for each log are then shown as they would be recorded for the three logs in the order that they were picked up by the skidder.

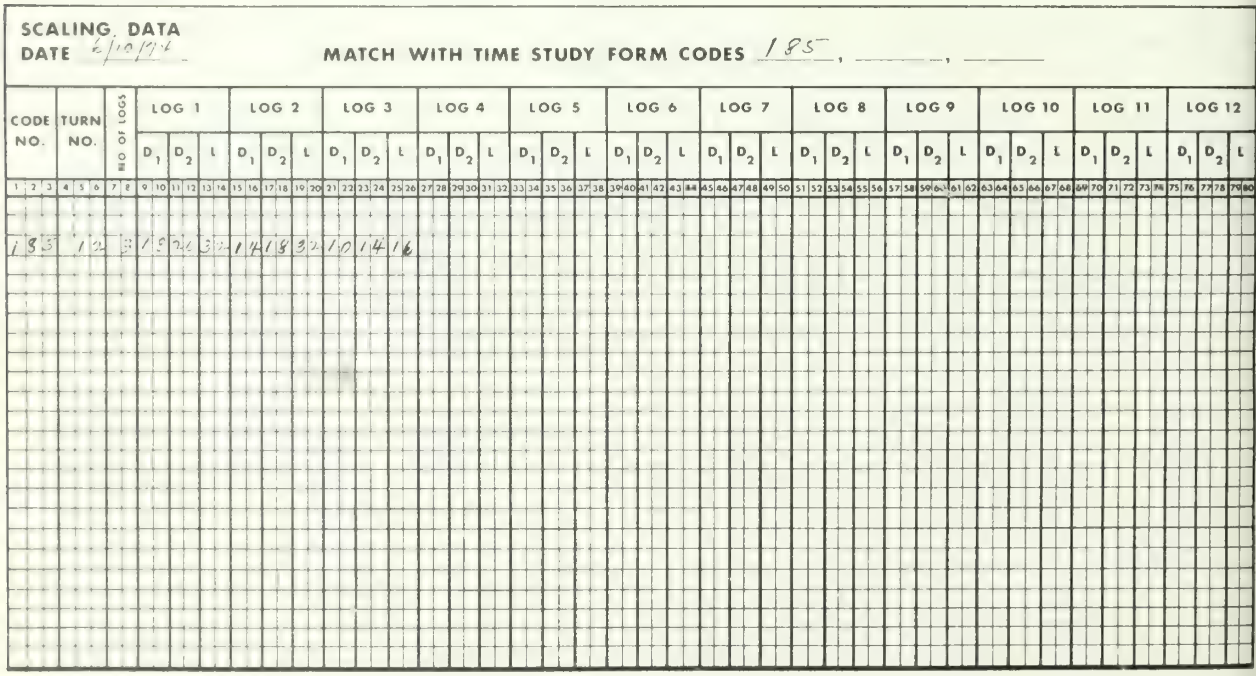


Figure 18.--Completed Scaling Data Form.

LOADING DATA FORM

The loading equipment used in the example timber sale is a hydraulic heel-boom oader (Prentice 600B). A time study is to be made to determine how independent ariables and subsystem interactions affect the loading operation. As in the two other ubsystems presented, initial conditions were documented on a Site-Terrain Information orm as shown in figure 19.

SITE/TERRAIN INFORMATION FORM

SITE DESCRIPTION

Logmaking ______ Location
Skidding ______ Timber Sale Clear Cut Unit #3
Yarding ______ Forest Targhee National Forest
Loading 250 Type of Cut Selective
Hauling ______ Contractor Idaho Mills, Inc.
Data Collection Date ______ Start Time 9:00 a.m. Stop Time 4:00 p.m.

Comments ______

SITE CONDITIONS

	Rating				
Surface Type	1	2	3		Comments ______
Surface Condition	1	2	3		Comments ______
Operator	1	2	3		Comments ______
Landing	1	2	3	4	Comments ______
Deck	1	2	3	4	Comments ______

Temperature 85 degrees Elevation 3400 ft
Wind 0 velocity — direction Precipitation 0 amount — form

SUBSYSTEM INFORMATION

Logmaking Comments ______
Crew Members
______, Comments ______
______, Comments ______
Saw or Feller
Make ______ Type ______ Equipment Owner ______
Model ______ Size ______ Payment (Method & Amount) ______

Skidding/Yarding Comments ______
Crew Members
______, Comments ______
______, Comments ______
______, Comments ______
Skidder or Yarder
Make ______ Type ______ Equipment Owner ______
Model ______ Size ______ Payment (Method & Amount) ______

Loading Comments ______
Crew Members
Bill Larsen (operator) Comments ______
______, Comments ______
Loader
Make Prentice Type ______ Equipment Owner Idaho Mills, Inc.
Model 600B Size ______ Payment (Method & Amount) $5.50/operating hour plus $20/day

Hauling Comments ______
Crew Members
______, Comments ______
______, Comments ______
Truck and Trailer
Make ______ Type ______ Equipment Owner ______
Model ______ Size ______ Payment (Method & Amount) ______

gure 19.--Completed te-Terrain Information rm--loading.

Flow Process Chart

Figure 20 is the flow process chart for a loading operation. The chart shows the elements or steps required to transfer logs from a deck to a truck trailer. Four elements constitute one loading cycle. Note that the chart applies equally to loading with either a grapple or tongs (which must be set by hand). Also note that certain elements may be combined or omitted as explained on the chart. Figure 21 illustrates a typical loading situation. Since the loader and trailer generally remain stationary throughout the loading operation, the observer has little difficulty finding a good, but safe, vantage point from which to collect data.

Form Entries

A copy of the Loading Data Form is given in figure 22. As in the case with the Mechanized Felling Data Form and Skidding Data Form, the Loading Data Form is constructed so that data can be directly transcribed to cards via keypunching.

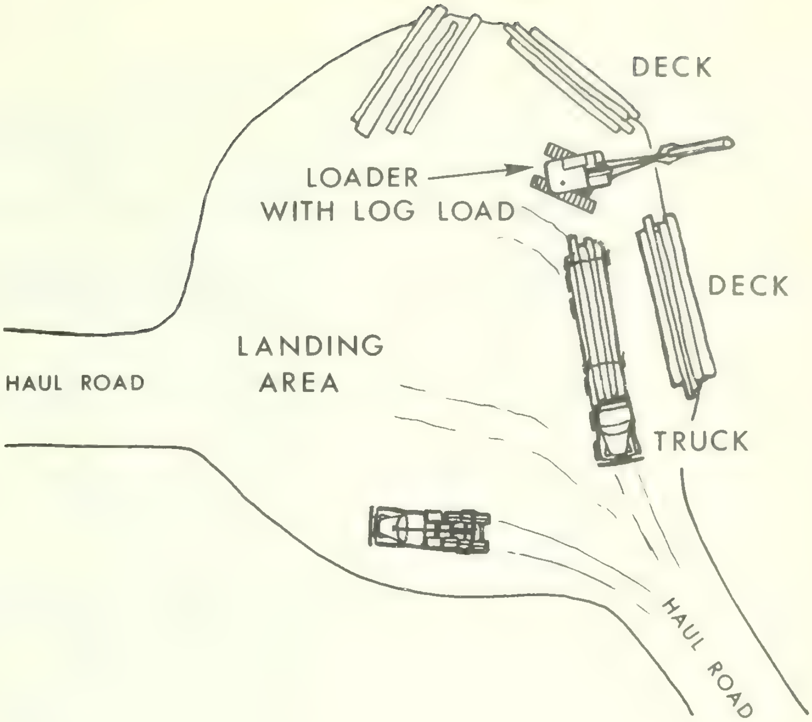
FLOW PROCESS CHART

SUBJECT CHARTED [illegible] BY ______
SUBSYSTEM [illegible]
METHOD USED ______

CHART SYMBOL	ELEMENT DESCRIPTION	ELEMENT BEGINNING & END POINTS
0	[illegible]	
1	Sort Log(s) ([illegible] Inspection and Movement)	Grapple attached to preliminary log load Grapple attached to final log load
2	[illegible]	Grapple attached to final log load Grapple disengaged from log load.
3	[illegible]	Grapple disengaged from log load Boom & grapple begin movement toward deck
4	[illegible]	Boom & grapple begin movement toward deck Grapple attached to log load
6	Logs Located on Truck	
NOTE	1 and 3 may be omitted;	
	[illegible], may not exist, on some cycles. Also when tongs are used 1 will be replaced by 1,	
	the [illegible] of setting tongs	

Figure 20.--Flow process chart--loading.

Figure 21.--Loading operation.



LOADING DATA–TURN ELEMENT TIME STUDY FORM AND KEYPUNCH TRANSCRIBING FORM
Snapback Reading

SUBSYSTEM	EQUIPMENT & METHOD	CODE NO.	TRUCK LOAD	1 SORT LOGS (HOOK TONGS)	2 MOVE LOAD	3 BUMP LOGS	4 MOVE UN.	FOREIGN ELEMENT	NUMBER OF LOGS	SPECIES	SLOPE (%)	SURFACE T	SURFACE C	OPERATOR	LANDING	DECK	I.D.	ADDITIONAL DATA	CONTINUE
1	2 3	4 5 6	7 8 9 10	11 12 13	14 15 16	17 18 19	20 21 22	23 24 25 26 27 28 29 30	31 32	33	34 35 36 37	38	39	40	41	42	43	44–79	80

Figure 22.--Loading Data Form.

An explanation of entries on the form follows:

Column	*Entry*	*Explanation*
1	Subsystem	One-digit entry identifies subsystem; per code shee
2-3	Equipment and Method	Two-digit entry identifies method used to accomplish subsystem function and also brand name and model used; per code sheet.
4-6	Code Number	Three-digit entry to identify observations and that matches with code number on Site-Terrain Informatic Form.
7-10	Truck Load No.	Up to a four-digit entry to identify load of logs. If possible, use truck driver's Load Slip No.
11-13	Sort Logs	Enter three digits representing time taken to perform element as defined on flow process chart. Enter time to nearest one-hundredth of a minute. *Note:* if tongs are used instead of a grapple, these columns can be used to record the time required to set tongs as, generally when tongs are used, sortir is usually not required.
14-16	Move Loaded	See explanation for col. 11-13.
17-19	Bump Logs	See explanation for col. 11-13.
20-22	Move Unloaded	See explanation for col. 11-13.
23-30	Foreign Element	As a group, these columns present information on foreign elements that occur. A foreign element is defined as an element that does not occur regularly on each turn. Enter single digit in col. 23 to identify foreign element type (per code sheet). Enter a single digit in col. 24 to identify regular element in which a foreign element occurred (se numbers above regular elements on Data Form). Enter up to three digits in col. 25-27 representing time elapsed in the regular element (entered in col. 24) when the foreign element began. Record time to the nearest tenth of a minute. Enter up to three digits in col. 28-30 representing time duration of foreign element. Record time to the nearest tenth of a minute.
31-32	No. of Logs	Enter digits representing number of logs loaded on truck during that particular cycle.
33	Species	Enter digit (per code sheet) representing species c log(s) loaded.

lumn	*Entry*	*Explanation*
-37	Slope	Enter percent slope from loader to truck being loaded. In most cases, this slope will be zero or nearly zero. A negative slope is recorded if the truck is at a level below the loader; positive slope is recorded if the truck is at a level above the loader.
8	Surface Type	Enter one digit classifying the surface type as outlined on the Site-Terrain Information Form.
9	Surface Condition	Enter one digit classifying the surface condition as outlined on the Site-Terrain Information Form.
0	Operator(s)	Enter a one-digit rating of operator's performance as outlined on the Site-Terrain Information Form.
1	Landing	Enter one digit classifying the landing area as outlined on the Site-Terrain Information Form.
2	Deck	Enter one digit classifying the deck as outlined on the Site-Terrain Information Form.
-79	Additional Data	Columns for additional data. Entries explained in next section.
0	Continue	An entry in the continuation column indicates that data pertaining to the current line of entry are continued to the next line on the data-gathering form. Any numeric digit, other than zero, may be entered in the continuation column. The continuation line will present data only in the additional data field.

Explanation of Entries in Additional Data Columns for Loading Data Forms

Additional data columns are used to record data pertaining to an observation when e prescribed columns of entry are not sufficient.

Following are additional data column entries for Loading Data Forms:

lumn	*Entry*	*Explanation*
3	Identification (I.D.)	Enter one digit (per code sheet) to identify reason that continuation was necessary.
-51	Foreign Element	When I.D. = 1, enter the second foreign element for that line according to previous instructions.
-XX	Scaling Data	When I.D. = 2, enter scaling data concerning logs loaded during that cycle. Such an entry requires six digits for each log as follows: (1) two digits for the small diameter in inches, (2) two digits for the large diameter in inches, and (3) two digits for the length in feet. The number of logs loaded is entered in col. 31-32. Other data pertaining to additions are entered according to defined conventions (i.e., the entry made in col. 44-XX will depend on the I.D. entry in col. 43).

When tongs are used and unhooking is required, this time can be recorded either in the additional data columns or as a foreign element, depending whether or not this element is required by the equipment (i.e., tongs are not designed to release automatically) or not, respectively.

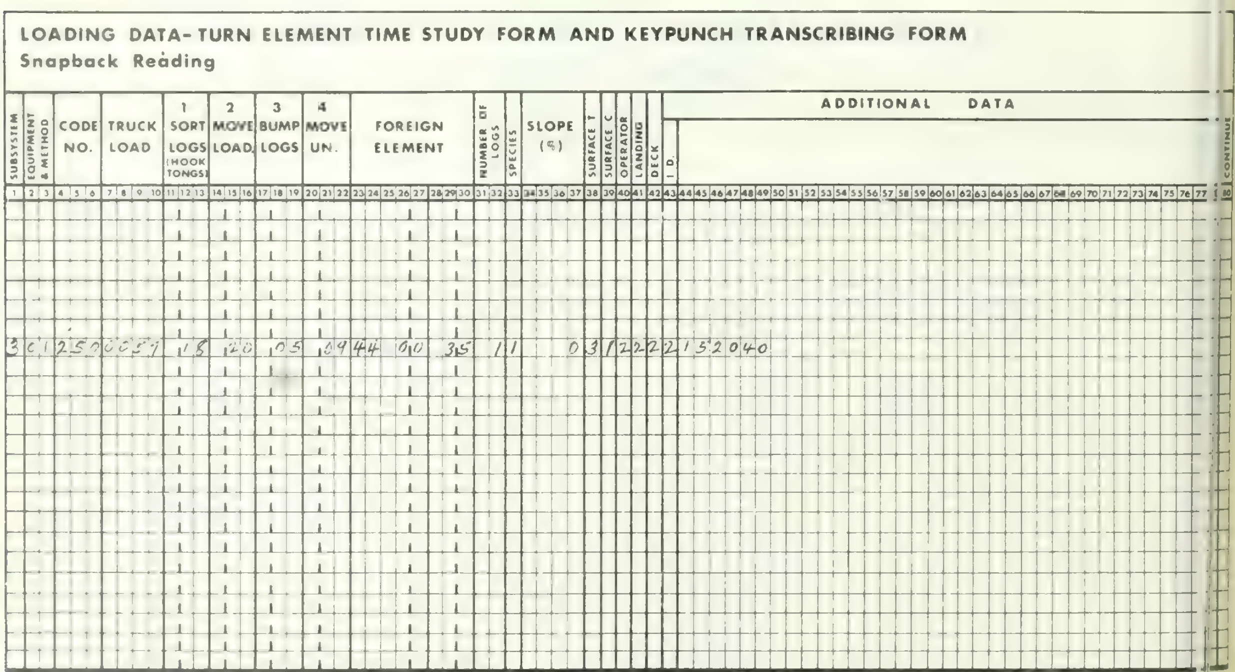
More than one foreign element (or other type of data) can be given in col. 43-79 Once the I.D. number is read, the computer is keyed for the number of columns to be read. After reading data related to the first I.D. number, the computer checks the next column for another I.D. number. For example, columns 43-79 have the capacity to accommodate data related to five foreign elements. Further, if col. 43-79 are used to capacity, additional data can be accommodated on the next line. In such a case, a numeric entry is made in col. 80.

Loading Data Example

The following is an example of a use of the Loading Data Form. Example entries are shown in figure 23.

Subsystem, Equipment and Method, and Code No. entries have been made in col. 1-6 and are the same for each cycle. On the eighth cycle, the grapple attaches to a log a sorts this log to a side deck in 0.18 minute. Then another is picked up and moved to the trailer, constituting the move-loaded element, in 0.20 minute. The log is releas on the trailer, but bumping is required which lasts 0.05 minute. Scaling data pertai ing to the log are entered in col. 44-49. Upon initiation of grapple movement towar the deck, the loader operator incurs a personal delay, or a type 4 foreign element, which lasts 3.5 minutes. The operator remounts loader and moves the grapple unloade from trailer to deck in 0.09 minute.

Other entries on the line, such as species, surface type, etc., are entered per the Site-Terrain Information Form. As noted on the explanation narrative of the Loading Data Form, entries in col. 1-6 and 34-42 generally need only be made once on each sheet unless changes in these data occur.


LOADING DATA-TURN ELEMENT TIME STUDY FORM AND KEYPUNCH TRANSCRIBING FORM
Snapback Reading

SUBSYSTEM	EQUIPMENT & METHOD	CODE NO.	TRUCK LOAD	1 SORT LOGS (HOOK TONGS)	2 MOVE LOAD.	3 BUMP LOGS	4 MOVE UN.	FOREIGN ELEMENT	NUMBER OF LOGS	SPECIES	SLOPE (%)	SURFACE T	SURFACE C	OPERATOR	LANDING	DECK	I.D.	ADDITIONAL DATA	CONTINUE
1	2 3	4 5 6	7 8 9 10	11 12 13	14 15 16	17 18 19	20 21 22	23 24 25 26 27 28 29 30	31 32	33	34 35 36 37	38	39	40	41	42	43	44–77	80
3	c 1	250	0057	18	20	05	09	44 00 35	1	1	0	3	1	2	2	2	2	152040	

Figure 23.--Completed Loading Data Form.

U S GOVERNMENT PRINTING OFFICE: 1975 — 677-328 / 14 REGION NO. II

Gibson, David F., and John H. Rodenberg
1975. Time study techniques for logging systems analysis. USDA For. Serv. Gen. Tech. Rep. INT-25, 32 p. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

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OXFORD: 524.41, 311, 301.
KEYWORDS: data recording methods, logging operations analysis, time study method.

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KEYWORDS: data recording methods, logging operations analysis, time study method.

Gibson, David F., and John H. Rodenberg
1975. Time study techniques for logging systems analysis. USDA For. Serv. Gen. Tech. Rep. INT-25, 32 p. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

The USDA Forest Service research work unit of Intermountain Station at Bozeman, Montana, has been engaged in recent years in a comprehensive logging systems analysis study. Together with other research work units, this unit has developed, field tested, and refined a system to gather time and motion study data on logging operations. Techniques and forms employed for certain types of operations are presented in this publication. Forms for other types of logging operations are to be issued as appendices to this publication.

OXFORD: 524.41, 311, 301.
KEYWORDS: data recording methods, logging operations analysis, time study method.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

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- Bozeman, Montana (in cooperation with Montana State University)
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AMERICAN REVOLUTION BICENTENNIAL
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FROM '76
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PORTABLE OSCILLOSCOPE TECHNIQUE FOR DETECTING DORMANCY IN NURSERY STOCK

Robert B. Ferguson, Russell A. Ryker, and Edward D. Ballard

USDA Forest Service General Technical Report INT-26, 1975
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Ogden, Utah 84401

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and Edward D. Ballard

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

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ABSTRACT

The proper timing for lifting nursery-grown planting stock is an important factor in the ultimate success of revegetation efforts on forest and range lands. This report describes a portable oscilloscope technique used to determine the level of activity or dormancy of nursery stock and plants in the field. The equipment includes a battery-powered oscilloscope and square wave signal generator, both commercially available, and a specialized electrode that must be constructed. A variety of plant species, including conifers and deciduous trees and shrubs, were monitored during all seasons of the year. Oscilloscopic wave form appeared to be related to periods of plant dormancy and activity. Certain similarities in wave form-seasonal relations were observed in related groups of plant species. The report describes the equipment used in detail, and suggests several potential uses to nurserymen and research workers.

INTRODUCTION

One of the primary factors affecting success in transplanting trees and shrubs is the degree of disturbance of the plant's physiological functions. When bare-root nursery stock is used for planting in the forest or on the range it has generally been believed that the best time to transplant is when the plants are dormant. Toumey and Korstian (1947) state that "planting should be done after growth ceases in autumn and before growth starts in spring."

To date, nurserymen have had to estimate the degree of dormancy of nursery stock by visual signs such as the development of terminal buds in autumn and the swelling and opening of buds in the spring. The proper timing for lifting nursery stock for field planting could be more precisely determined if a reliable method for monitoring physiological activity was available.

Wanek (1971) tried to assess the degree of dormancy by the shape of an oscilloscope trace when a square wave electrical pulse was applied to a Douglas-fir needle. He obtained differences in trace shape that he felt might indicate life or death of plant tissue, as well as a trace shape that he thought indicated dormant tissue.

Zaerr (1972) evaluated oscilloscope trace shape as an indication of injury or death of plant tissue following exposure to freezing, steaming, or treatment with an herbicide.

Following correspondence with Wanek and Zaerr in early 1972, we conducted additional research to determine whether a reliable technique could be developed for determining plant dormancy, utilizing portable oscilloscope equipment. This report is intended primarily as a guide for others in obtaining and using the portable oscilloscope and square wave generator. In addition, it summarizes our observations on numerous plant species.

FALL LIFTING APPLICATION

The portable oscilloscope technique has been used since the autumn of 1974 as an aid in determining dormancy of coniferous planting stock before fall lifting at Lucky Peak Nursery near Boise, Idaho. Although no research has been done to determine whethe planting success will be increased as a result of using the oscilloscope, it is hoped that the technique will improve the timing of fall lifting.

Our experience is that appearance on the oscilloscope screen of the square wave pattern believed to indicate full dormancy does not correspond with complete development of winter buds. The square wave appears 2 or more weeks after winter buds are fully developed. The time lag seems to vary with the year, species, seedling age, seedling density in beds, and watering schedules.

EQUIPMENT

Equipment to provide readings of physiological activity in plant tissue includes an oscilloscope, square wave generator, electrode, and connecting cables. For practica field use, the system must be lightweight and include its own power sources.

The system described here can be assembled in a suitable carrying case for field use. We used an attache case 18 inches long, 13 inches wide, and 7 inches deep (fig. 1 In this arrangement the components and case weigh about 15 pounds.

Portable Oscilloscope

For all our experiments, we used the Tektronix Model 211 oscilloscope (fig. 2). The unit may be obtained from Tektronix Inc., 14150 S. W. Karl Brown Dr., Beaverton, Oregon 97005. Federal agency personnel may refer to FSC Group 66, Part II, Section G, Contract No. GS-005-13175.

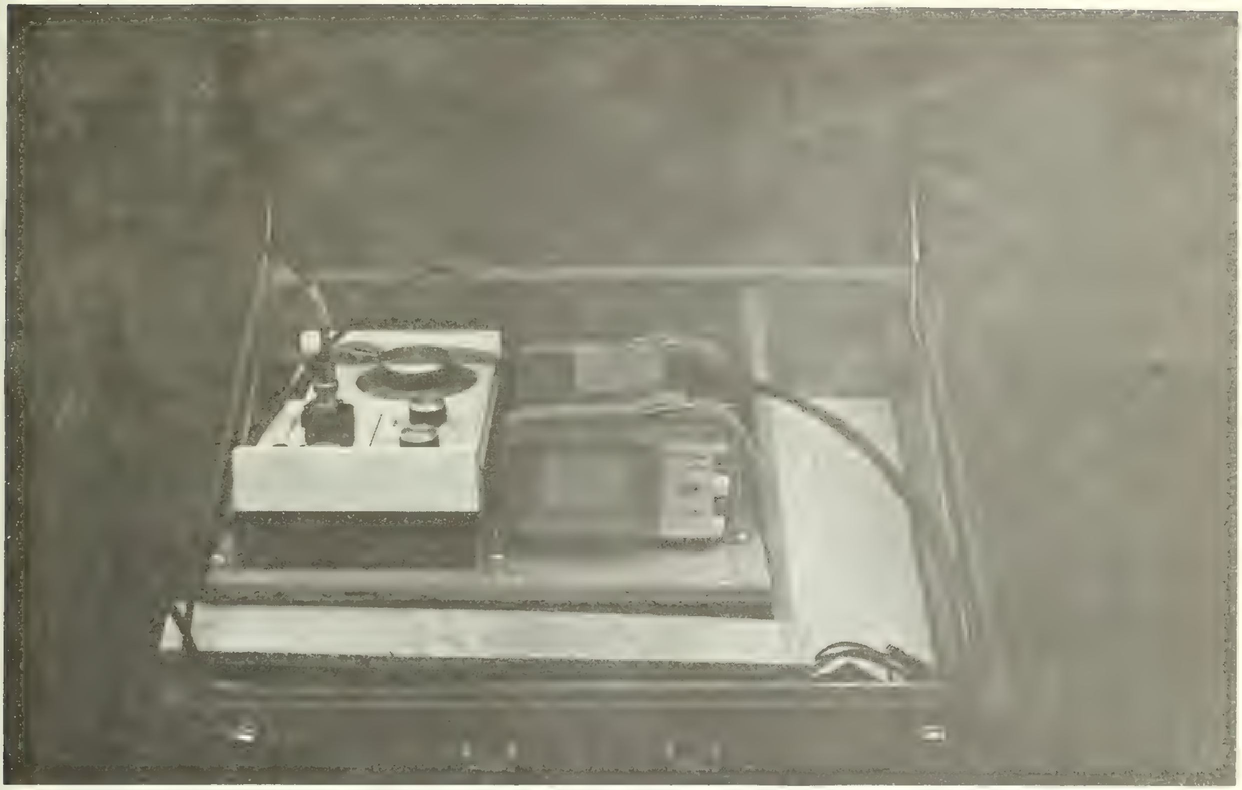

Figure 1.--Portable oscilloscope and square wave generator assembled in a single carrying case for field use.

Figure 2.--The Tektronix Model 211 battery-operated, portable oscilloscope.

Portable Square Wave Generator

Our original battery-powered square wave generator was constructed by Edward D. Ballard. The Wavetek Model 30 generator (fig. 3) performs the same function, is commercially available, and is somewhat more versatile.

The Model 30 is manufactured by Wavetek, P. O. Box 651, San Diego, California 9211 The manufacturer will supply a list of distributors.

To familiarize readers with easily available equipment, the connection and control setting instructions in this report apply to the Model 30 generator. The research observations reported here were made with a system including the unit constructed by Ballard.

Figure 3.--The Wavetek Model 30 battery-operated square wave generator.

Electrode

An electrode must be constructed to transmit the square wave electrical pulse through plant tissue.

Our electrode (fig. 4) consists of four stainless steel surgical needles embedded in clear plastic and connected to two 4-foot coaxial cables. Electrode construction details are given in the appendix.

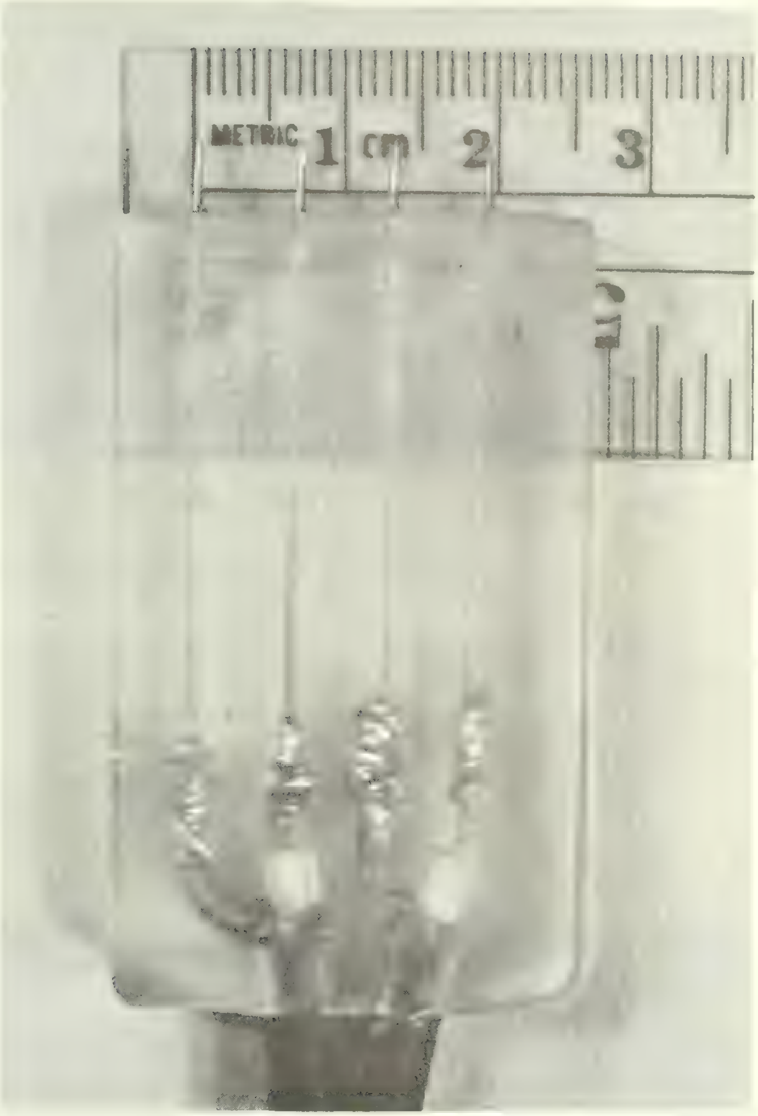

Figure 4.--Electrode used to transmit square wave signal through plant tissue. Stainless steel needles are spaced about 7 mm apart.

PROCEDURE

Oscilloscope readings can be taken in less than one-half minute per plant after units are properly connected and controls are set. Before starting the procedure, set controls on the side panel of the oscilloscope (fig. 5):

Control	*Setting*
VOLTS/DIV	Calibrate (CAL)
HORIZ MAG	Calibrate (CAL)
TRIGGER (LEVEL/SLOPE)	Auto preset
TRIGGER (INT-EXT)	INT
INPUT COUPLING	AC

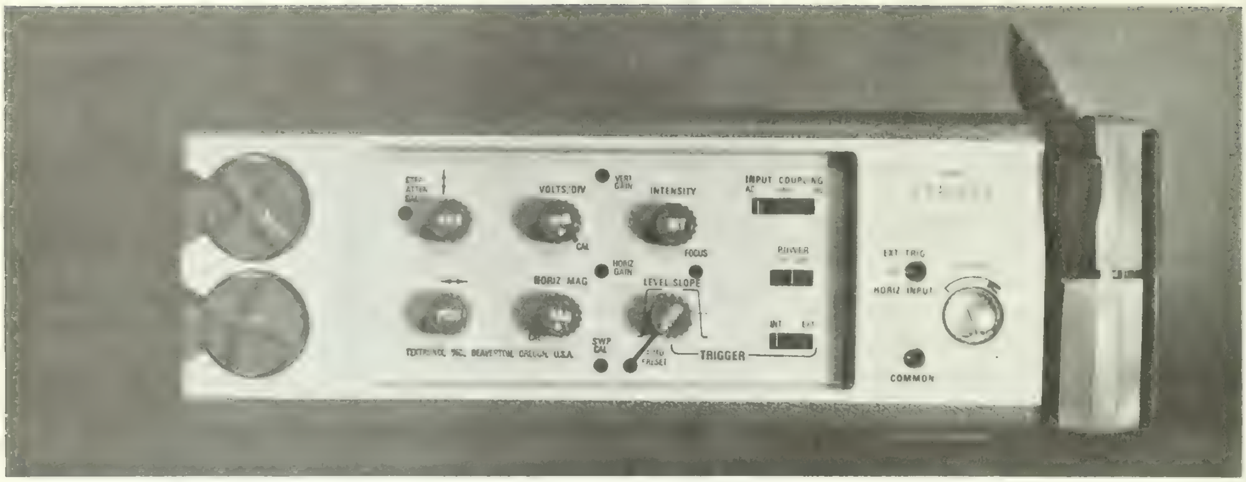

Figure 5.--Side panel of controls for the Tektronix Model 211 oscilloscope.

Set the SEC/DIV control on the front of the oscilloscope at 0.2 m and turn the frequency scale dial of the generator to 8.5 and the range switch to X100. Then:

1. Turn on the oscilloscope.

2. Insert the electrode needles well into the plant tissue (just below the terminal bud for nursery stock; fig. 6). If stem or twig diameter is small enough, push the needles completely through. After the needles are firmly embedded, do not touch them because trace shape will be affected.

Figure 6.--Electrode needles embedded in nursery seedling for reading.

3. Turn on the square wave generator. Waiting until after the electrode needles are embedded in the plant minimizes battery drain.

4. Adjust other oscilloscope controls as necessary to clearly view the trace. Frequently, the VOLTS/DIV control on the front of the oscilloscope will require adjustment to increase the amplitude to near full-screen height. To avoid battery drain, set the INTENSITY control only as high as necessary to provide a good image. Adjust the position controls to center the trace.

Visibility of the trace on the screen can be improved when using the system outdoors by attaching the plastic shade provided with the oscilloscope. We have recorded signal traces by photographing the screen with a 35 mm camera using standard black and white film. The photograph may include VOLTS/DIV and SEC/DIV control settings, which may be useful if the same plant is tested later.

INTERPRETING WAVE TRACES

Figure 7 shows drawings of the general forms of oscilloscope traces that we interpret to indicate active, fully dormant, and dead tissue. The square wave will pass through the tissue essentially unchanged, though decreased in amplitude, if the tissue is dormant. If the tissue is active, the wave form will be peaked on the left edge and decrease in height toward the right. Dead plant tissue, whether wet (as when boiled) or dry, exhibits a sawtooth wave form on the oscilloscope.

In most plant species we have studied, the changes from dormancy to activity in the spring and from activity to dormancy in the fall are gradual. The leading (left) edge of the square wave shows only a small peak during the transition periods. We have observed considerable variation in the length of transition periods, which may be due to species differences or to variations in microenvironment.

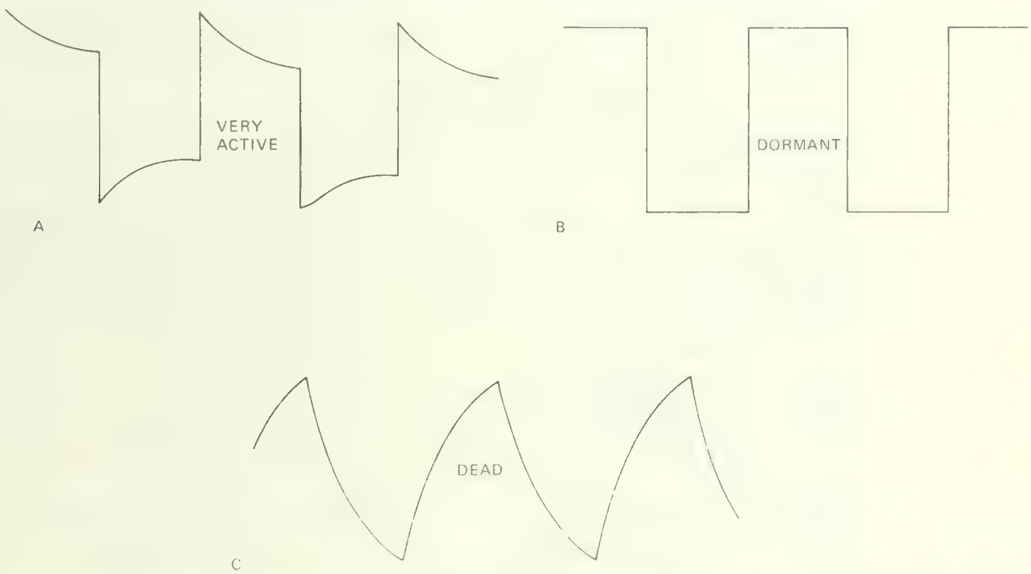

Figure 7.--Patterns of oscilloscope traces that indicate (A) active, (B) dormant, and (C) dead tissue.

RESEARCH

Test Procedures

In mid-October 1972, six tree species and one shrub species were chosen for periodic testing with the portable oscilloscope. These plants were located at the Lucky Peak Nursery (elevation 3,200 feet). Plants were tagged so that readings could be made on the same specimens on each observation date.

In March 1973, a number of native tree and shrub species were selected for observation. These plants were located in Boise County along State Highway 21, beginning at an elevation of 6,200 feet near Mores Creek Summit, and ending at 4,500 feet elevation at Fan Creek, 8 miles north of Idaho City. Plant species selected at each location were:

LUCKY PEAK NURSERY

Larix occidentalis	Western larch
Picea engelmannii	Engelmann spruce
Pinus contorta	Lodgepole pine
Pinus ponderosa	Ponderosa pine
Populus deltoides	Cottonwood
Pseudotsuga menziesii	Douglas-fir
Purshia tridentata	Antelope bitterbrush

BOISE COUNTY TRANSECT

Abies lasiocarpa	Subalpine fir
Acer glabrum	Douglas maple
Alnus incana	Mountain alder
Amelanchier alnifolia	Saskatoon serviceberry
Ceanothus velutinus	Snowbrush ceanothus
Cornus stolonifera	Redosier dogwood
Pinus ponderosa	Ponderosa pine
Populus tremuloides	Quaking aspen
Prunus emarginata	Bitter cherry
Pseudotsuga menziesii	Douglas-fir
Rhamnus purshiana	Cascara buckthorn
Salix scouleriana	Scouler willow
Sambucus cerulea	Blue elderberry
Sorbus scopulina	Greene's mountain ash
Symphoricarpos oreophilus	Mountain snowberry

Between January and May 1973, several species of trees and shrubs were tested in the vicinity of the Intermountain Station's Forestry Sciences Laboratory in Boise (elevation 2,700 feet).

Using the portable equipment, readings were taken of intact stem tissue. During the autumn, winter, and spring of 1972-1973 the readings were taken on terminal or lateral twig growth of the 1972 growing season. As soon as new growth had elongated enough in 1973, it was usually used for the reading.

The needles of the probe were pushed firmly into the twig (entirely through if the twig was small enough). With the oscilloscope turned on, the square wave generator was set at 1 volt output and the generator switched on. The horizontal sweep adjustment of the oscilloscope was set at 0.2 millisecond per division, and the vertical deflection control tuned to obtain approximately full scale amplitude. A 35 mm camera was used to photograph each trace display. The entire procedure could easily be completed in half a minute.

We found that only a single reading was necessary on each plant, since similarly shaped traces were obtained whenever the probe needles were embedded in similar positions of the plant. For example, readings were similar when taken near the tip of the youngest woody tissue.

Three plants of each species sampled at the nursery were read. At other locations only one reading was usually taken for each species, though occasionally several readings were made for verification. From early April to October 1973, some phenological notations were recorded for most species on the dates that readings were obtained.

Results and Discussion

At the beginning of the field study in October 1972, five of the seven species located at the nursery exhibited trace shapes similar to those illustrated by oak (*Quercus* sp.) and bitterbrush in figure 8. We interpret this as indicating that the portion of the plant into which the probe has been inserted has become dormant. The remaining two species, Douglas-fir and western larch, exhibited trace shapes having a slightly raised leading edge (illustrated by arborvitae in figure 8), indicating less impedance of the high frequencies. We interpret this to indicate continued activity of the plant tissue being tested. By October 31 and November 14, western larch and Douglas-fir, respectively, exhibited the dormant trace. There was little variation in trace shape between plants of the same species.

Through the months of November, December, and January all species at the nursery location remained dormant. However, at the lower elevation of the City of Boise a horticultural variety of mockorange (*Philadelphus* sp.) exhibited a conspicuously raised (peaked) leading edge on January 22. This was the only species showing this trace shape out of 14 species of trees and shrubs checked on that date in Boise.

On February 14, lodgepole pine and western larch at the nursery exhibited slightly peaked traces. The larch was lifted from the seedbeds before any further observations could be made. Douglas-fir indicated slight activity on February 21.

On February 26 only three of the 14 species sampled at Boise were slightly active: mockorange, Pfitzer juniper (*Juniperus chinensis pfitzeriana* Spaeth.), and golden currant (*Ribes aureum* Pursh). By March 20 only a species of arborvitae (*Thuja orientalis* L.) had joined these three species in exhibiting a peaked trace. Other deciduous tree and shrub species, as well as Colorado blue spruce (*Picea pungens* Engelm.) still showed square or slightly rounded traces.

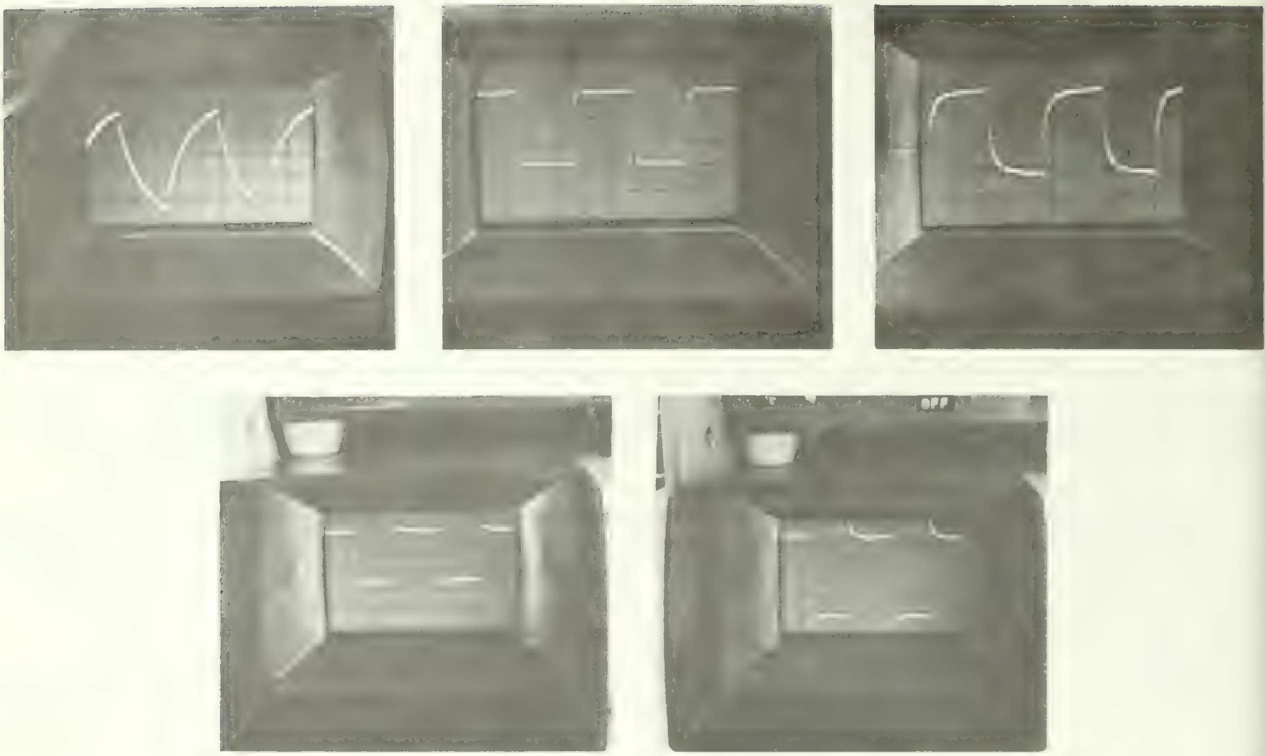

Figure 8.--Oscilloscope traces obtained when a square wave signal is transmitted through dead plant tissue (upper left), dormant plant tissue (oak, upper center; and bitterbrush, upper right), slightly active plant tissue (arborvitae, lower left), and active plant tissue (barberry, lower right). The trace indicating dormancy may vary from nearly square to a form more rounded on the leading edge.

On March 23 we began observations at the Boise County transect. Only Douglas-fir exhibited a slightly peaked trace (while at the lower elevation nursery site, ponderosa pine and Douglas-fir now showed slight activity). By April 4, both Douglas-fir and ponderosa pine exhibited an increasingly greater peak on the leading edge of the trace (similar to the illustration for barberry (*Berberis* sp.) in figure 8). On April 19 only Douglas-fir showed a peaked trace along the Boise County transect, and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) had become active at the nursery. By May 4, subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) was active at 6,200 feet elevation and cottonwood (*Populus deltoides* Marsh.) was active at the nursery.

The sequence continued into the summer until all species exhibited a peaked trace shape. Figure 9 presents the approximate length of the dormant and active periods for several species selected from those sampled during 1972 and 1973. Local climatic variation probably affects the length of the dormant period for most plant species.

Electrical Circuit Responses

Oscilloscopes and square wave generators are routinely used in electronic repair shops to test the response of electrical circuits. The usefulness of the square wave for circuit testing lies in the nature of the wave form. The square wave is a complex wave form composed of many sine waves--a fundamental frequency and all its harmonics. Therefore, it permits in one operation, testing of circuit response to a wide range of frequencies.

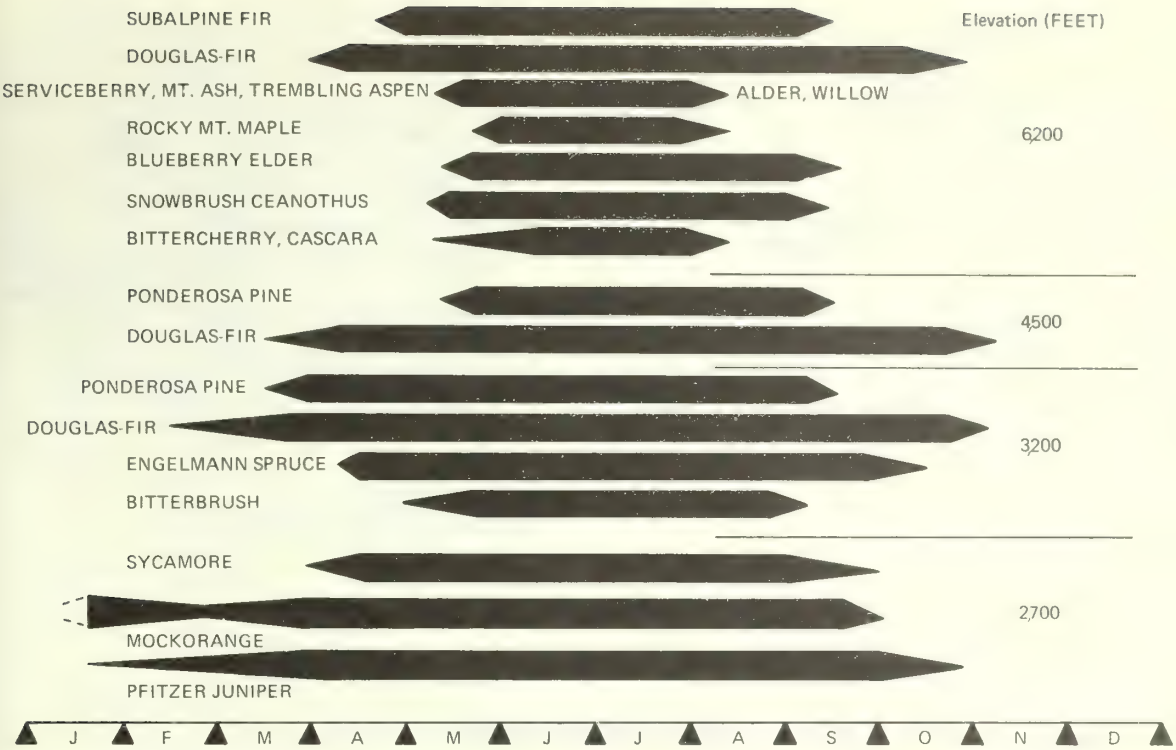

Figure 9.--Length of active period for selected species of trees and shrubs at four different elevations.

In assessing the degree of a plant's physiological activity with this equipment, we are testing the response characteristics of an electrical circuit in the plant. The section of twig between the electrodes can be represented by an electrical circuit consisting of elements of resistance and capacitance connected in series and parallel (DePlater and Greenham 1959).

Hayden and others (1969) proposed a model for the electrical circuit in plants. Its essential components are cell wall resistance, cytoplasm resistance, and cell membrane resistance and capacitance (fig. 10). Changes in the physiological status of the plant presumably change capacitance at the cell membrane, and are reflected in changes in wave form on the oscilloscope. Resistance is independent of frequency, while capacitance and frequency are related as shown in the formula for capacitive reactance (X_c):

$$X_c = \frac{1}{2\pi fC}$$

The formula shows that as capacitance and frequency increase, the opposition to current flow decreases. This effect shows up on the oscilloscope as a peak at the left edge of the square wave (fig. 7a). This occurs at the time plants are active. If capacitance should decrease, the opposition to current flow would increase and the wave form would gradually return to the square wave shape (fig. 7B). This seems to occur at the time plants enter the dormant state. At death, capacitance is lost resulting in high frequency cutoff. This is distinguished by a sawtooth wave form (fig. 7C). We do not know what changes in the plant result in an increase or decrease in capacitance, but changes in cell membrane thickness and permeability are suspected factors.

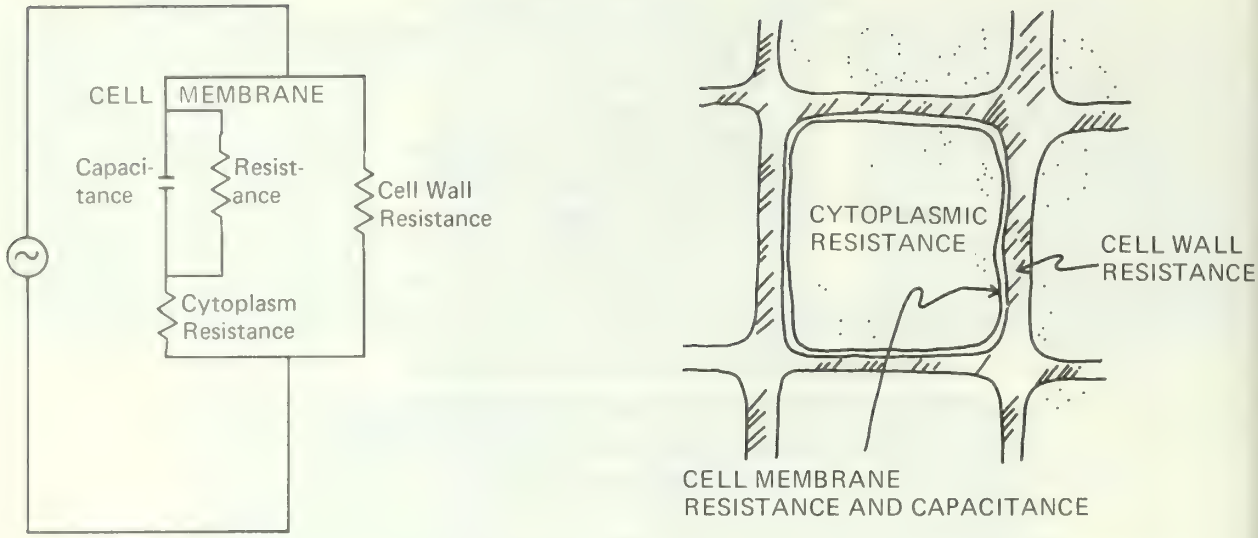

Figure 10.--An electrical model proposed by Hayden and others (1969).

Research Needs

We have observed a tendency toward similarity in wave form between related species For example, nearly all species of the family Pinaceae exhibited dormant season wave forms having no slope to the left. The one exception was a nursery-grown western larch seedling. These same species seldom exhibit an active season wave form that slopes to the left before peaking. However, the majority of deciduous shrub species exhibited wave forms that sloped to some degree, both during the dormant and active seasons. More intensive observations of many plant species are needed to determine how much consistency in wave form exists in specific groups of plants.

We have assumed that the increase or decrease in the impedance of the high frequency components of the square wave signal reflect changes in electrical characteristics that occur at the time the plant enters or leaves dormancy. We still need to learn exactly what is happening in the plant tissues at the time we obtain various wave forms on the oscilloscope screen. Has growth (cell division and expansion) stopped when we can no longer detect any peak of the square wave? What effect does moisture content of the plant tissue have on wave form?

POTENTIAL USES

It is likely that additional work with this type of electronic equipment will reveal a number of ways in which it can be used to reveal changes in the physiological activity of plant tissue. If the probe could be miniaturized, the activity of smaller plant parts such as buds, conifer needles, or the vascular systems of the leaves of deciduous trees and shrubs could be monitored.

The portable oscilloscope and square wave generator might also be used to evaluate the relative frost hardiness or cold tolerance of biotypes within a species, or between different plant species. Possibly, the effect of other environmental influences (such as heat or drought) could be evaluated through oscilloscope readings.

This technique might also be valuable in the examination of nursery stock during storage to assess the effects of storage conditions. It also may be useful to determine activity in target and nontarget plants in vegetation control projects where growth stage is critical in achieving success.

The advantage of utilizing interpretations of changes in the square wave shape to assess physiological status of plant tissue is that factors such as tissue temperature and depth of penetration of the electrodes do not seem to significantly affect wave form, while impedance measurements such as discussed by Evert (1973) and Glerum and Krenciglowa (1970) are influenced by such factors.

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APPENDIX

Equipment Development and Details

Portable Oscilloscope

The Tektronix Model 211 oscilloscope is battery-operated, 3.0 inches high, 5.2 inches wide, and 8.9 inches long. The Model 211 is a triggered, single channel, 500 kHz instrument using all solid state and integrated circuit components except for the cathode ray tube.

Vertical deflection is calibrated from 1 millivolt to 50 volts per division. For the range of 10 millivolts to 50 volts, the bandwidth is from DC to at least 500 kHz. Input resistance is approximately 1 megohm. Input capacitance is approximately 130 picofarads. Horizontal deflection is calibrated from 200 milliseconds to 5 microseconds per division.

Portable Square Wave Generator

Our original battery-operated square wave generator was constructed to generate a square wave signal at a fixed frequency of 1,000 Hz, ±20 percent, with an amplitude variable from 0 to 15 V. This signal generator was 5.0 inches wide, 3.4 inches high, and 6.0 inches long, as viewed from the face. It was strapped to the top of the oscilloscope (fig. 11), and the two instruments were carried in a specially made leather carrying case. All tests reported in this paper were made with this generator.

The Wavetek Model 30 (fig. 3) is a battery-operated, self-sweeping audio function generator. Frequency ranges are 2 Hz to 2 kHz, 20 Hz to 20 kHz, and 200 Hz to 200 kHz. The generator is supplied with a conventional 9-V transistor battery, which will operate the generator for a full 8-hr day. A rechargeable nickel-cadmium battery and charger can be supplied as an option, which gives unlimited operation time when left connected to the line voltage.

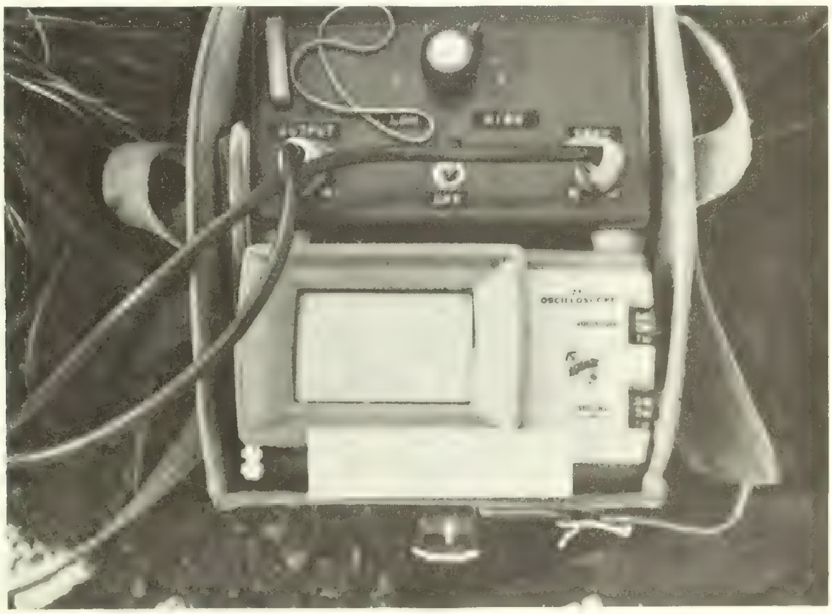

Figure 11.--Portable oscilloscope and square wave generator assembled in a home-made, leather carrying case. The square wave generator shown here was constructed by E. D. Ballard.

Electrode

Zaerr's electrode was constructed of four silver pins 0.64 mm in diameter arranged in a straight line. The pins were coated with silver chloride, spaced 2 mm apart, and inserted in a plastic block so that only the tips protruded. A square wave signal at a frequency of 100 Hz and with a peak-to-peak amplitude of 5 V was applied to the first pin. The second and fourth pins were connected together to ground and the third pin to an electrometer. The output from the electrometer was connected to one channel of a dual beam storage oscilloscope. The other channel of the oscilloscope displayed the square wave input to pin 1 of the electrode.

Surgical needles in the electrode constructed for our experiments are 0.64 mm in diameter above the tapering point. Before securing the four needles in a fixed position by embedding them in clear plastic, we confirmed Zaerr's observation that minor differences in needle spacing had no effect on shape of the oscilloscope trace obtained from plant tissue. There was, however, a slight increase in peak-to-peak amplitude when needles were more closely spaced.

The needles of the electrode are embedded in plastic at a spacing of about 7 mm (fig. 4). Two 4-foot coaxial cables (RG-58 A/u) are used to connect the electrode needles to the signal generator and oscilloscope (fig. 12). Needle 1 is connected to the output terminal of the square wave generator, needle 3 is connected to the oscilloscope vertical input terminal, and needles 2 and 4 are connected to ground. Needles 2 and 4 are connected together with a short piece of hookup wire.

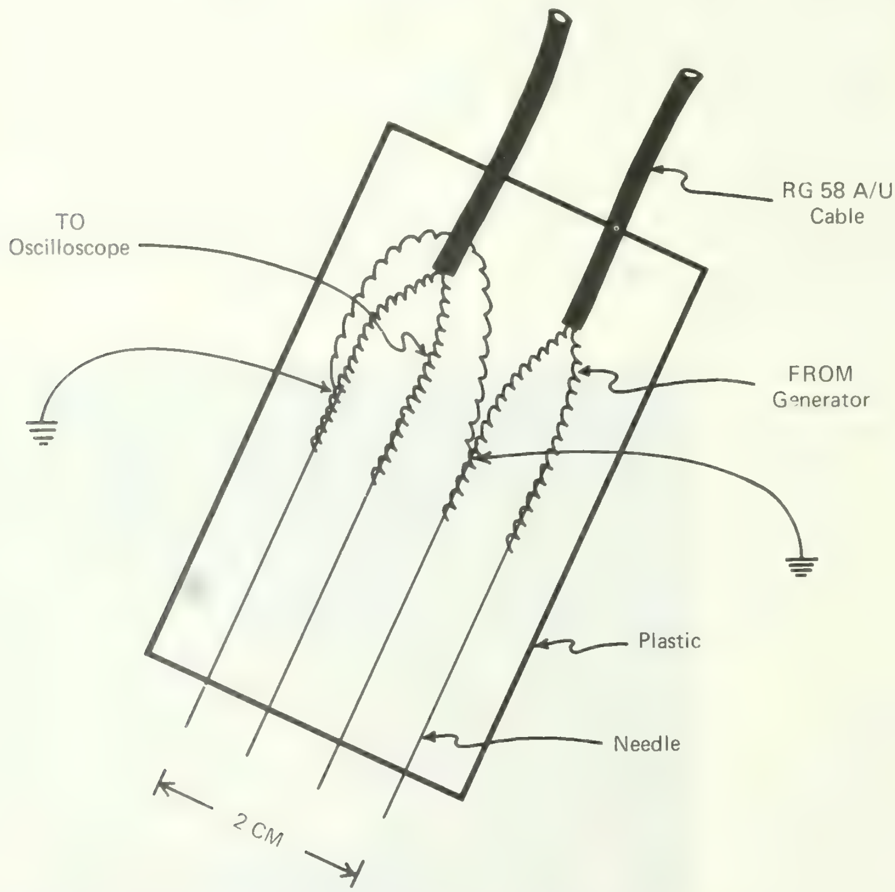

Figure 12.--Schematic illustrating electrical connections used in constructing the electrode.

U.S. GOVERNMENT PRINTING OFFICE 1975—677-328 / 27 REGION NO.8

Ferguson, Robert B., Russell A. Ryker, and Edward D. Ballard
1975. Portable oscilloscope technique for detecting dormancy in nursery stock. USDA For. Serv. Gen. Tech. Rep. INT-26, 16 p., 7 ref. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

This report describes the use of a portable oscilloscope and square wave generator system for determining the physiological activity of nursery stock. Observations on a number of tree and shrub species throughout all seasons of the year are presented, and additional potential uses for the technique are suggested.

OXFORD: 161, 165.622, 232.32, 232.41.
KEYWORDS: planting stock, dormancy, plant physiology, oscilloscope, nursery methods.

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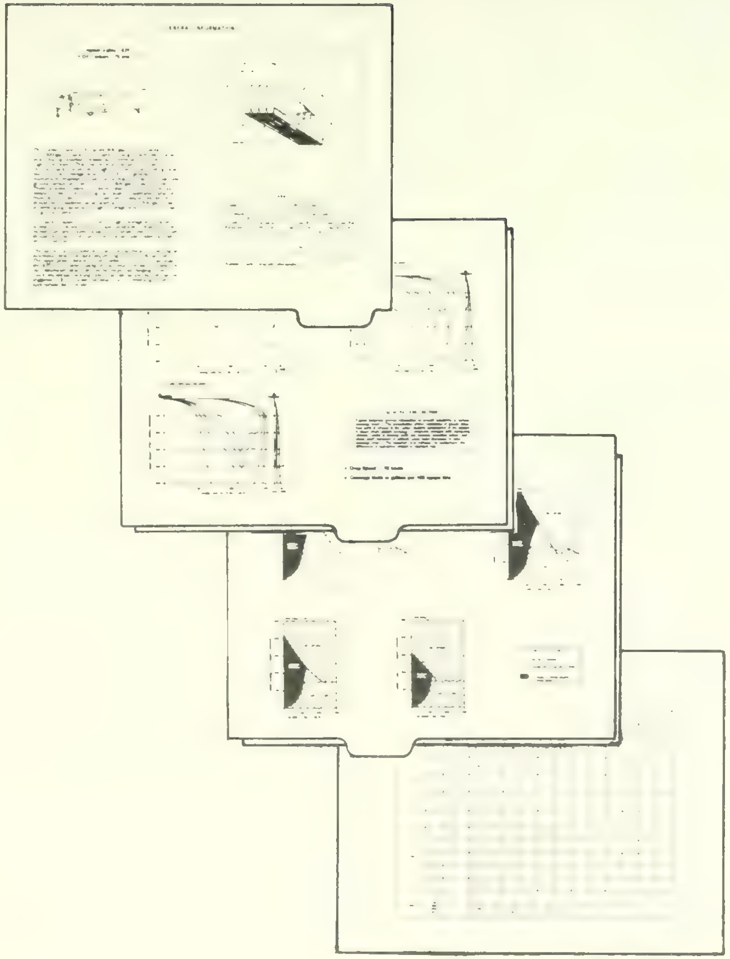
AMERICAN REVOLUTION BICENTENNIAL
1776-1976

GROWING FROM '76
U.S. FORESTRY CENTENNIAL



AIR TANKER PERFORMANCE GUIDES:

GENERAL INSTRUCTION MANUAL

D. H. Swanson, C. W. George, and
A. D. Luedecke

USDA Forest Service
General Technical Report INT-27
INTERMOUNTAIN FOREST AND
RANGE EXPERIMENT STATION

AIR TANKER PERFORMANCE GUIDES: GENERAL INSTRUCTION MANUAL

by

D. H. Swanson, Honeywell Inc.
C. W. George, USDA Forest Service
A. D. Luedecke, Honeywell Inc.

This manual is published as a part of a program to improve fire control technology through the use of fire-retarding chemicals and delivery systems designed for specific fuels and fire situations. Information or questions regarding these studies and requests for performance guides for specific aircraft should be directed to the authors at:

Northern Forest Fire Laboratory
Drawer G
Missoula, Montana 59801

or

Honeywell Inc.
Government and Aeronautical Products Division
600 Second Street Northeast
Hopkins, Minnesota 55343

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- Δ Introduce a basis for systematic planning so that specific air tankers can be employed in the most effective manner based on their inherent capabilities or limitations and the local fire/fuel situation.

- Δ Provide (in association with other guidelines) the ability to relate performance of one tanker to the capabilities of other tankers that may be brought into the area.

- Δ Introduce a procedure for evaluating tanker operations so that the most effective method for dropping can be identified for the local situation.

Air tankers differ considerably in their capabilities and limitations because of tank design, tank sequence options, retardant quantities, and aircraft flight characteristics. When an aircraft, in concert with the locally available retardant and usage patterns refined over years of practical experience, is singularly effective in a local fire/fuel situation, that aircraft will become an acknowledged favorite. A different aircraft assigned to the same task may appear totally ineffectual by comparison, even though it too may be a favorite in other regions where usage patterns, retardants, or the like are different.

Recently, the understanding of tanker performance has been advanced at the Northern Forest Fire Laboratory. If we know what makes a good drop from one aircraft in a given local situation, we can adjust the usage pattern of a different aircraft to most closely approximate performance of the favored tanker. We can also begin to recognize situational changes from day to day or hour to hour that influence delivery conditions--that change the drops delivered in identical ways from excellent to poor between morning and afternoon.

reason, many of the baseline values issued in these guidelines are points of departure that should be refined based on experience and intelligent experimentation. The guidelines will, if properly used, provide a method of quantitatively assessing the good drops versus the bad drops.

For example, if your favorite aircraft is covered by the guides available, think back to a drop that was particularly effective. By estimating drop height at tank release you can determine from the curves presented the pattern value and certain other characteristics of the pattern. These characteristics, then, provide the critical viewpoint by which we refine our intuition and subsequently attempt to tailor the performance of air tankers for most effective usage. Recordkeeping is an important part of guidelines application.

Although experience is invaluable in developing usage patterns for the local situation, even better ways of using favorite aircraft can be found. Some of the views presented here may seem inconsistent with your understanding of aerial firefighting; nonetheless, our views, intuitions, and habits of employing the air tanker have evolved from the water bomber to current retardant aircraft.

Past recommendations are weighted heavily by the preponderance of TBM's and other low-capacity aircraft. They are influenced by firefighting with conventional hoses (and there are both similarities and startling differences). Because of this influence, current aircraft usage may be less than optimum. This document therefore provides, in addition to guidelines, a basis for experimentation, so that even better usage patterns can be identified for more efficient and effective fire management through the use of air tankers.

Guides for specific aircraft that have been evaluated are available from:

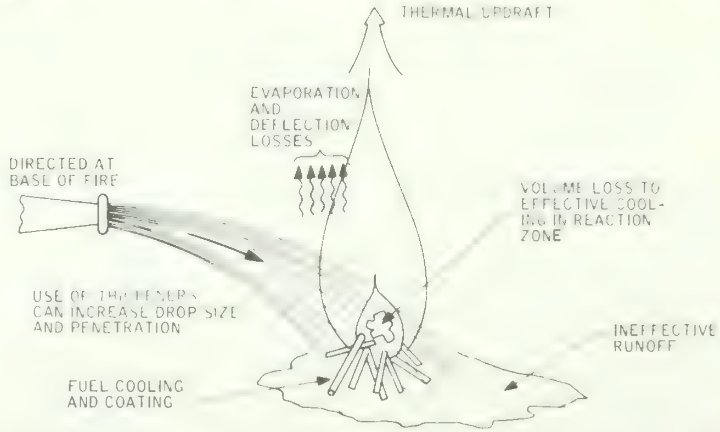
The Northern Forest Fire Laboratory
Drawer G
Missoula, Montana 59801

CONVENTIONAL FIREFIGHTING HAS SOME SIMILARITIES TO AIR TANKER ATTACK

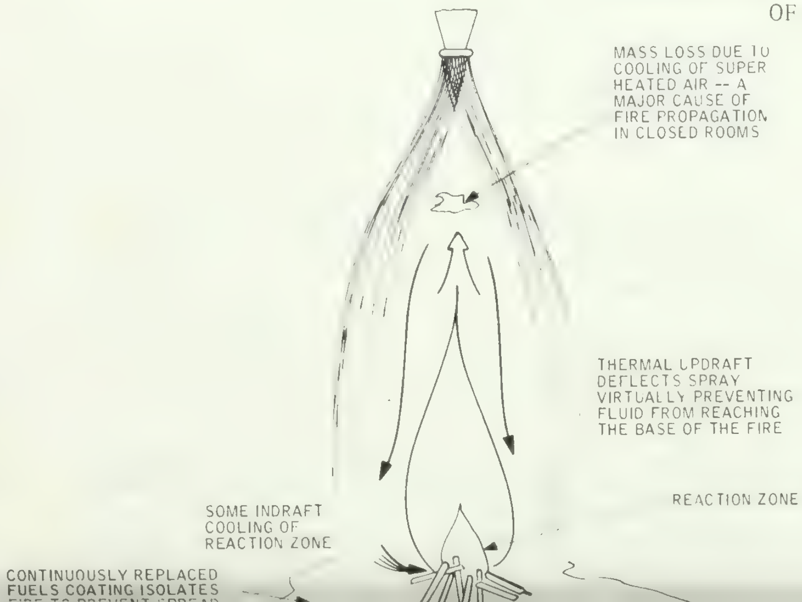
In conventional firefighting, retardant or water is continuously applied to completely extinguish the fire by several means:

- Cooling fuels and gases near the reaction zone.
- Coating fuel surfaces to deprive the surface of heat and oxygen.

Optimized techniques attempt to tailor application rates (gal/sec) to reduce time of application by minimizing runoff--the amount of material that is not effective in achieving extinction.



A SPRINKLER SYSTEM OPERATES FROM ABOVE THE FIRE--ILLUSTRATING BOTH THE PROBLEMS AND PRINCIPLES OF AIR TANKER ATTACK



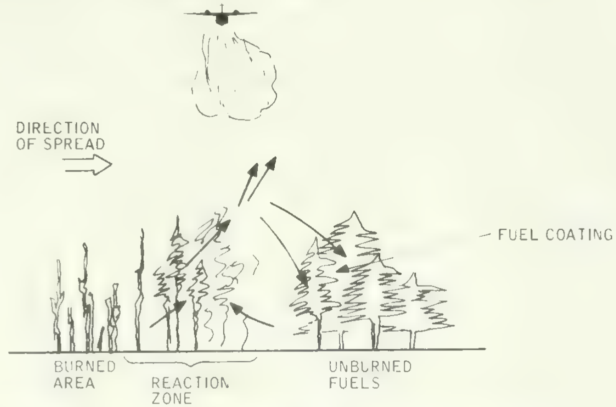
A sprinkler system is not generally credited with the capability of direct suppression because the thermal updraft protects the flame like an umbrella. Instead, it operates against the fire-spread mechanisms by cooling the superheated air and "fireproofing" adjacent fuels.

Thickeners increase drop size, and consequently their penetration into the fire plume.

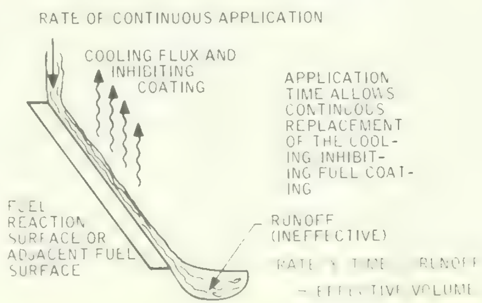
combination of a driving wind and thermal updraft largely deflects drops toward the fuels in front of the fire.

Unlike the sprinkler, mass losses taken in cooling superheated air above the fire do little to reduce the spread rate since radiation from the convection column does not contribute significantly to fire spread.

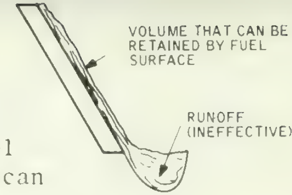
Fuel coating (from water content and thickeners), fuel modification (from the retardant salts), and fuel cooling (from the water content) are the major fire-suppressing agents in retardants.



Conventional firefighting uses time of application to cool or starve the fire to extinction.

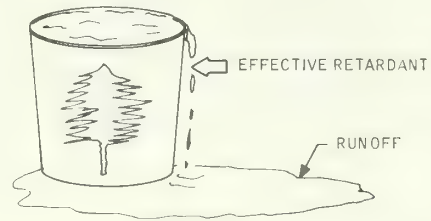


retain an adequate amount to extinguish, knock down, or retard the fire.



Effective volume is that retained by the fuel surface. The addition of thickening agents can increase the volume retained on the fuel and slow runoff.

Since the fuel surfaces are limited in the amount of retardant they can retain, any excess application will ultimately be lost as runoff.



This factor places practical limits on the useful coverage levels in retardant ground patterns.

It also means that in most cases of direct attack, retardant effects on adjacent fuels are as significant as those on the reaction zone itself.

FIRE: Although dripping and running prolong the continuous effects of the brief application, the total effect is limited to what can be achieved in something less than one minute -- few fires are extinguished by conventional techniques in a matter of minutes regardless of application rate.

LONG-TERM BENEFITS: The retardant salts continue to alter pyrolysis of combustion mechanisms long after the water content has been dissipated. This effect becomes more significant in aerial retardant delivery than the benefits of fuel cooling and coating from the water content of the retardant alone.

SHORT-TERM BENEFITS: Limit of the short-term benefits of fuel cooling and coating from the water content of retained retardant. If the effect lasts long enough to resist fire spread to new fuels, delayed extinction will result.

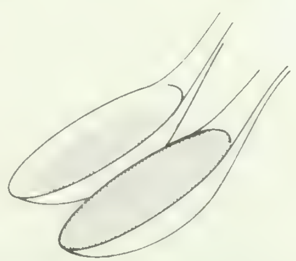
RECOMMENDED COVERAGE LEVELS

Recommended coverage levels are based on studies of fuel surface capacities, retardant salt effects, moisture damping effects, and knowledge of the pattern capabilities of aircraft known to be effective in certain fire situations. The coverage levels are related to fuel models contained in the National Fire Danger Rating System.

[illegible] LEVEL	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible] AN[illegible] H [illegible]
	[illegible]	HARDWOO[illegible] LITTER AFTER [illegible]
	H	[illegible] CONIFER TIMBER WITH LITTER ON[illegible]
[illegible] OR MORE	B	HAR[illegible] CHAPARRAL AN[illegible] OTHER [illegible] FLAMMABLE SHR[illegible]BS
	[illegible]	[illegible], OLD CONIFER TIMBER WITH LITTER AND DEAD, DOWN LIMB WOOD
		CONIFER SLASH

[illegible] CREEPING OR SMOLDERING FIRES, REDUCTION OF ONE COVERAGE LEVEL MAY BE CONSIDERED.

Coverage levels expressed in gallons per 100 square feet (gpc), are derived from the fuel surface area and the effect of retardant salts on spread rate in typical fuels. Coverage levels are tempered by personal knowledge of aircraft performance in certain fire situations. For example, the Bureau of Land Management has confidence in the use of trail systems against grass fires. Such systems produce considerable line at levels ranging from 0.5 to 2 gallons per 100 square feet.



ONE GALLON PER 100 SQUARE FEET IS ABOUT 1 1/2 TABLESPOONS SPREAD EVENLY ON THIS PAGE

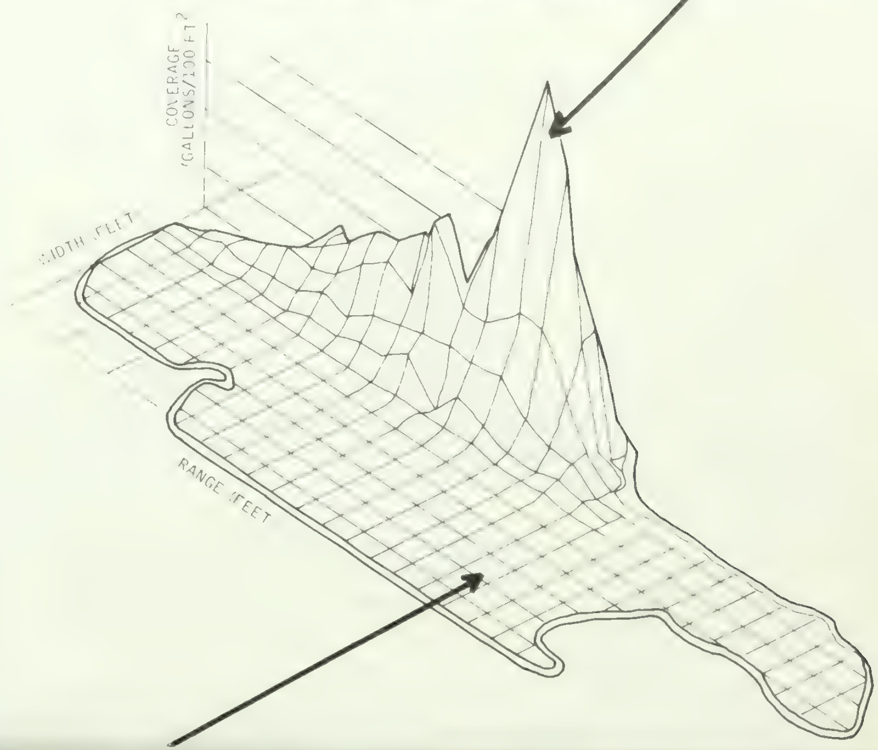
EVEN AT HIGHER COVERAGE LEVELS THE AMOUNT IS NOT GREAT -- IT IS EQUIVALENT TO THE DEPTH OF MATERIAL BELOW

RETARDANT PATTERNS

A retardant pattern maps retardant distribution on the ground in terms of effective coverage levels. The pattern provides a means for evaluating the effects of the drop on the fire fuels by examining the area, length, and width of the pattern at its various coverage levels.

This three-dimensional representation of the retardant pattern resembles a mountain range emerging from a plateau. It shows how the coverage level, measured in gallons per 100 square feet, fluctuates over the drop area. The vertical coverage level is greatly exaggerated here.

A. The mountain range contains the coverage levels of 1 to 4 recommended in these guides.



specific coverage levels, the pattern's effectiveness can be evaluated in various fire situations.

- Δ Considerable areas of the pattern are at coverage levels in excess of that required. They are effective, but the excessive gallonage could be better used if spread over a larger area.

- Δ Some areas are inadequately covered. They have more limited effectiveness and may in many cases be ignored.

There are three important characteristics of any pattern.

- Δ Length at a given coverage level.

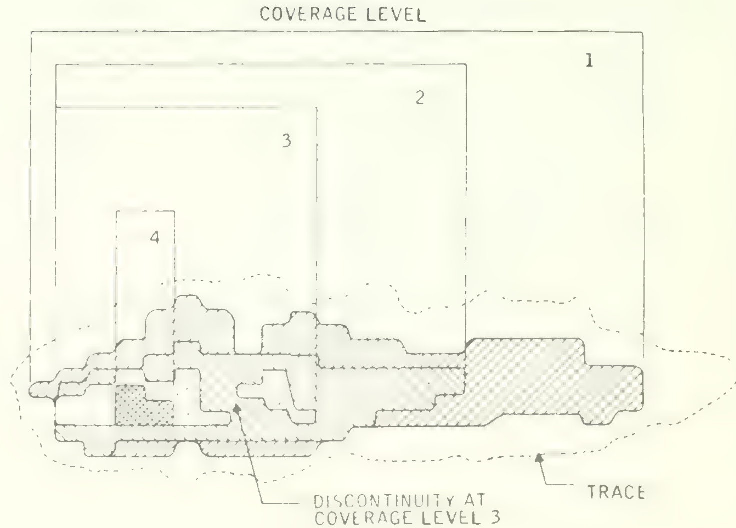
- Δ Width at a given coverage level.

- Δ The momentum of the retardant mass as it falls to the ground.

LENGTH is a direct measure of the line applied in front of the fire. It is also the pattern dimension that accommodates range errors in placing the pattern accurately. Length is controllable by proper selection of the tank release options available to the pilot.

WIDTH is the pattern dimension that accommodates cross-range errors in placing the pattern. Its influence on the fire is difficult to evaluate quantitatively, and it is not generally controllable. Increased width is viewed as a benefit, but is not considered variable in these guidelines.

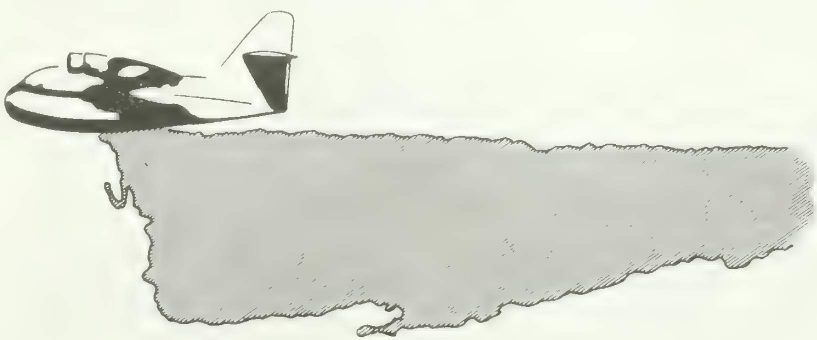
MOMENTUM refers to the velocity and mass of the retardant as it approaches the ground. It determines where the central core of the pattern will land with respect to the release point. High-momentum drops shoot far down range from the release point, resist wind deflection, and penetrate most fire plumes. They yield small areas at very high coverage levels and have the potential to physically break fuel structures (top trees, etc.). As a consequence they are potentially dangerous to ground personnel. The high-momentum portion of the pattern contributes to accuracy and is usually limited to the lower drop heights.

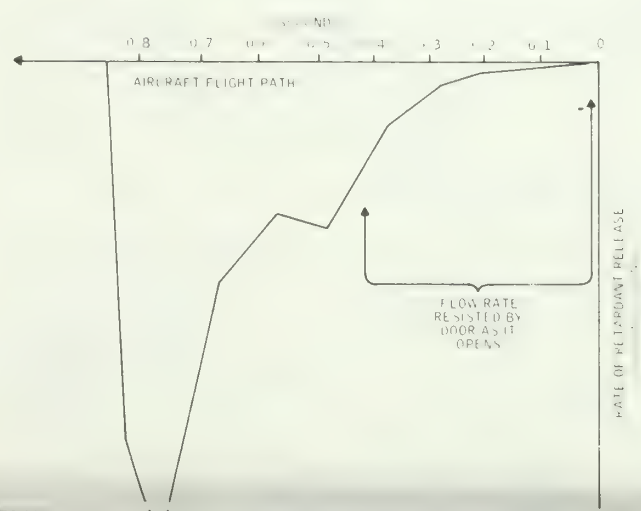


VOLUME FLOW RATE ESTABLISHES TANK AND GATING SYSTEM PERFORMANCE

Volume flow rate from the tank determines retardant distribution pattern. Aircraft velocity, altitude, and retardant type simply modify retardant distribution on the ground.

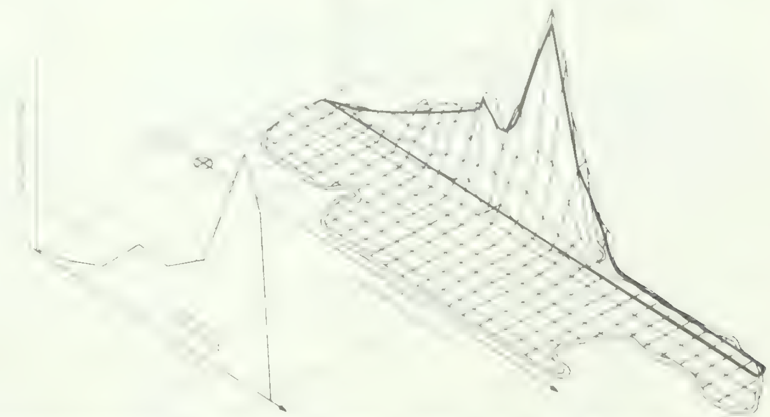
The flow rate from the CL-215, for example, has the basic form shown below, which is determined by tank geometry, door opening rate, venting, and door area.



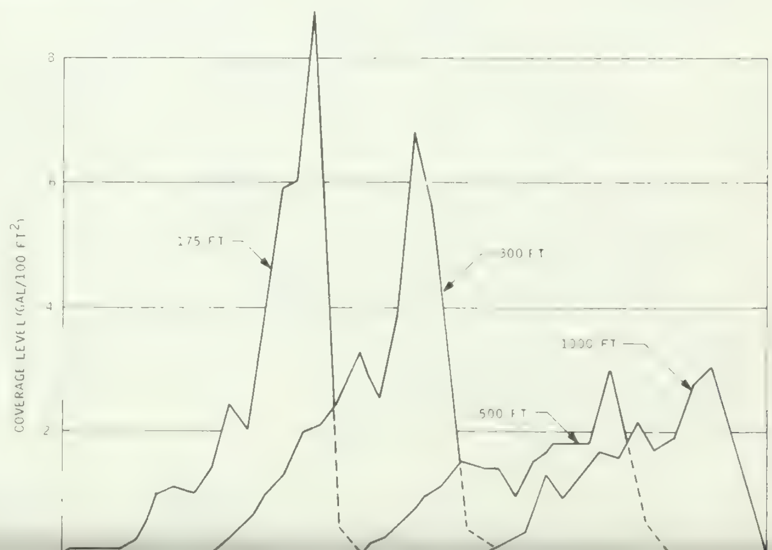


FLOW-RATE-DETERMINED PATTERN CHARACTERISTICS ARE VISIBLE IN RECOVERED GROUND PATTERNS

The three-dimensional plot below shows how flow-rate distribution is reflected in the ground-coverage pattern.

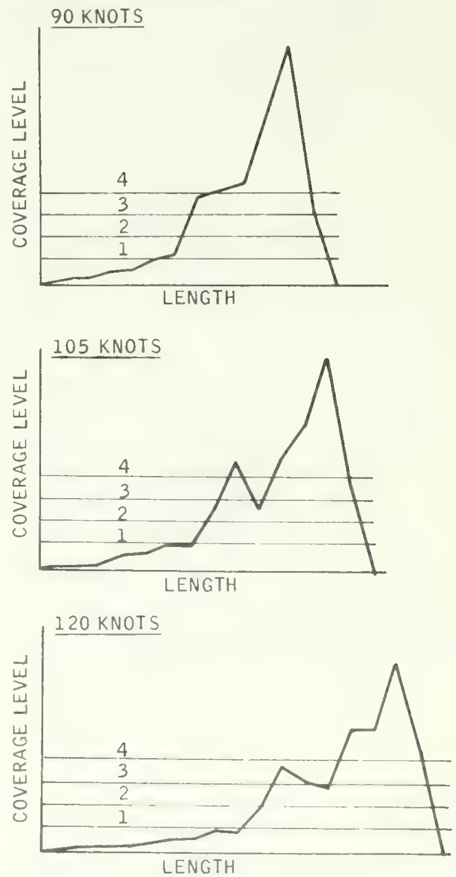


Flow-determined characteristics are retained regardless of the altitude even though actual coverage levels are reduced as the retardant spreads out in width, and loses material to evaporation.



rate, tank geometry, venting, and door area. The distribution of retardant in the pattern can be controlled to a limited extent by the selection of aircraft drop height, velocity, and angle of attack.

PATTERN PROFILES



DROP HEIGHT--Increasing the drop height reduces the peak coverage level and momentum of the pattern, and increases pattern width. Its effect on pattern length ranges from small to great depending on the tank design and the retardant type. Because it affects the pattern, aircraft, and ground safety, drop height is a primary variable in these guides.

AIRCRAFT VELOCITY--The aircraft velocity with respect to the ground changes the retardant distribution as shown, but its effect on coverage levels is not usually as significant as might be supposed. Flying faster will generally reduce peak coverage values, increase pattern momentum, and increase low coverage lengths. All data in these guides are based on the midvelocity of specific aircraft.

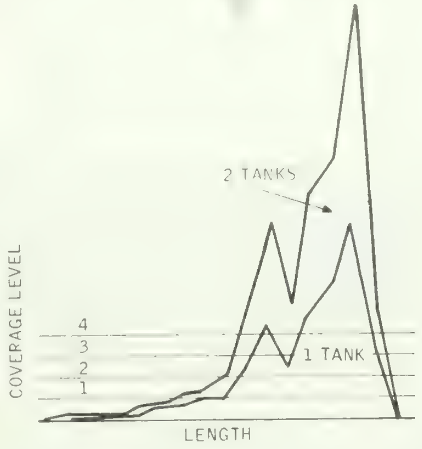
AIRCRAFT MANEUVER--The effects of dive or toss modes of release are similar to effects of velocity. Diving tends to foreshorten the pattern and increase coverage levels. The effect is similar to reducing velocity. Toss tends to elongate the pattern. The effect is similar to increasing aircraft velocity. Maneuver selection is more related to the ability to place the pattern accurately than it is to the coverage levels obtained. It is not considered a primary variable in these guides.

WIND--The effect of wind is to deflect the pattern and greatly increase the pattern's fringe area. It does not generally diminish pattern area or length significantly at the 1- through 4-gallons-per-hundred-square-feet coverage levels. Like drop height, wind will exert a greater influence on water-like retardants, than on gum-thickened products. The smaller drops are more susceptible to drift, deflection, and increased evaporation losses than the larger drops of gum-thickened retardants. Because the effect is more related to placement accuracy than coverage, all data in the guides are generated under a theoretical no-wind condition.

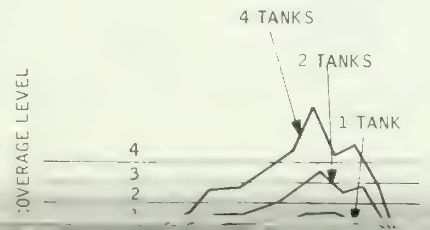
NUMBER OF TANKS DETERMINES AIRCRAFT FLEXIBILITY

Most aircraft carry at least two tanks; some contain as many as eight. Considerable control can be exerted on the pattern by the judicious use of the tanking increments available and the time between tank releases.

Δ Dropping two tanks simultaneously (in salvo) doubles the flow rate and, consequently, the coverage level. It does not necessarily double the length or the area of useful coverage.

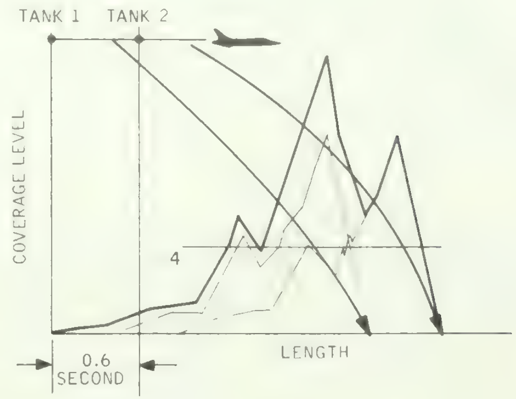


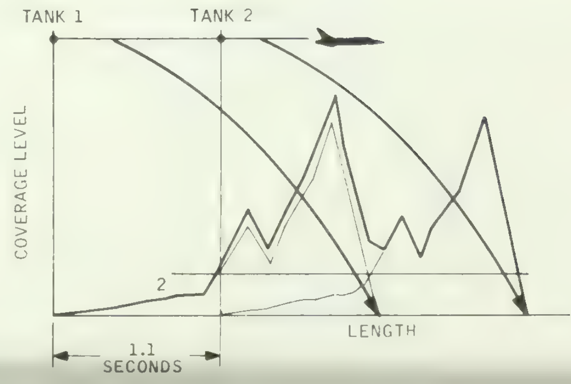
Δ For some tanking systems, multiple-tank salvos are useful to bring pattern coverage up to the appropriate values: To accommodate the effects of increased altitude or to increase flexibility.



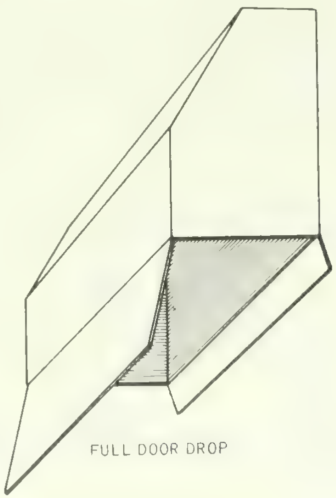
PATTERN CAN BE CONTROLLED BY A DELAYED RELEASE SEQUENCE

In most cases, the most efficient use of multiple tank drops occurs when individual tank releases are spaced along the aircraft flight path. The appropriate delay interval will vary with drop height, aircraft velocity, retardant type, and the desired coverage level. Few aircraft are equipped to regulate delays accurately. Nonetheless, delays can be approximated to maximize pattern length at the required coverage level.

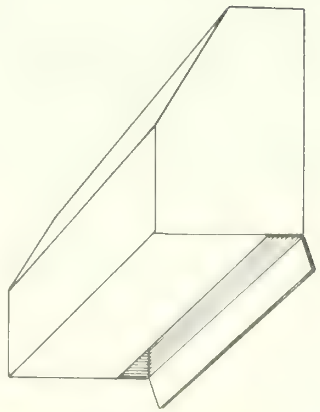




Depending on the desired pattern level, all or part of the tank bottom can be opened.



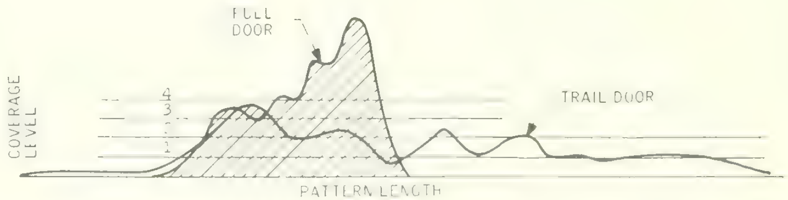
FULL DOOR DROP



TRAIL DOOR DROP

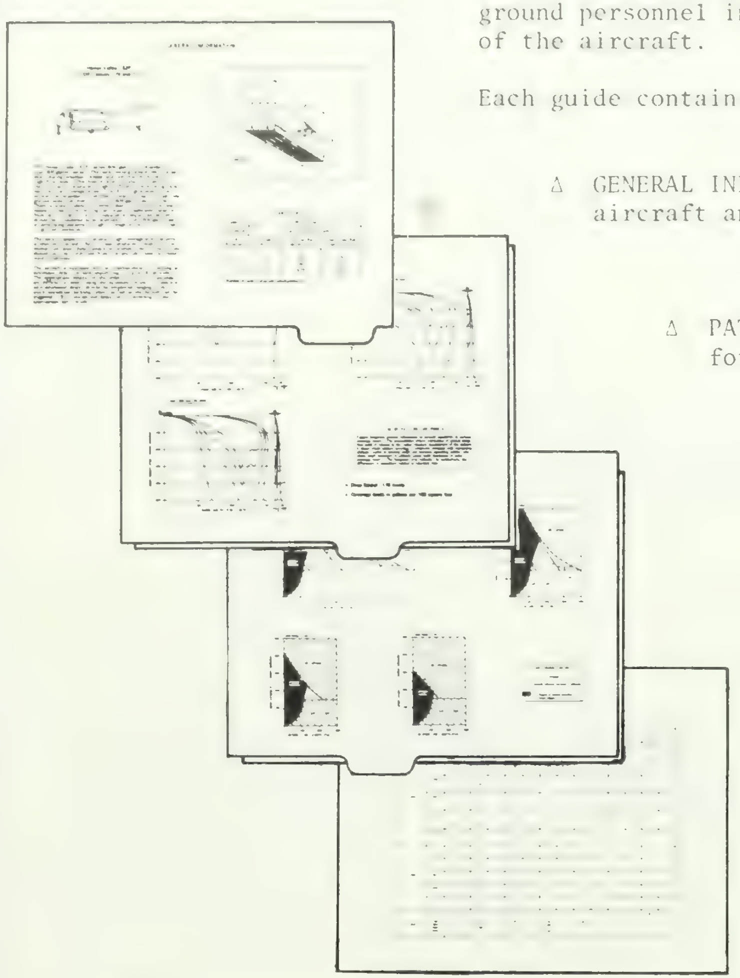
Flow Rates Available From One Tank With Two Door Options. . . .

. . . .Yield Two Types Of Ground Pattern



ORGANIZATION OF USER GUIDES

The User Guides display data on specific aircraft, in forms useful to the tanker pilot, air attack, and ground personnel in achieving the most efficient use of the aircraft.



Each guide contains:

- Δ GENERAL INFORMATION--A brief description of the aircraft and its tanking system.
- Δ PATTERN FOOTPRINTS--Plots of pattern coverage levels for various types of drops and retardants.
- Δ BEST STRATEGY CHARTS--Enabling quick selection of the best number and sequence of tanks to be employed for specific coverage requirements and line length.
- Δ DETAILED TABLES--Showing the line length and specific settings for delayed release to achieve maximum coverage at a large number of coverage levels and altitudes.

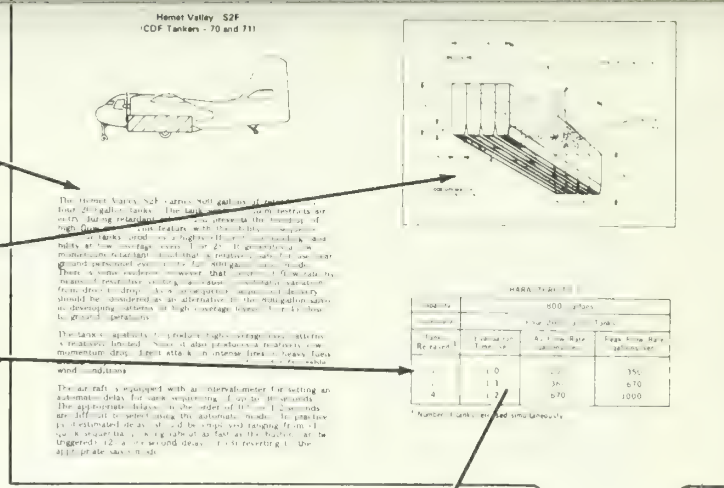
The following pages discuss the use of this information.

The general information section contains three elements:

- Δ A description and assessment of the aircraft tanking system in terms of its limitations and capabilities. It is particularly useful in comparing the aircraft with others that might be used in the region, so that differences in tankers' employment are apparent.

- Δ A schematic of the tank showing the pattern control options available.

- Δ A table of characteristics showing typical tank evacuation times, retardant capacities, and average and peak flow rates.



Hemet Valley S2F
CDF Tankers - 70 and 711

Using these data, it is possible to compare aircraft quickly. Performance similar to that of a familiar aircraft will generally occur under conditions where the average flow rates are comparable. For example: A 1,000-gallon tank with a 235-gallons-per-second flow rate is known to produce patterns effective against fires in your region. A new tanker with four 200-gallon tanks becomes available that offers 200-, 400-, and 800-gallons-per-second flow-rate options. Comparable coverage levels (but considerably shorter patterns) will be obtained using the 200-gallons-per-second (single tank) release under similar delivery conditions. Conversely, if an 800-gallon tank with 1,000-gallons-per-second peak flow has been used effectively in close-support operations, an apparently comparable 750-gallon tank producing a 2,000-gallons-per-second peak flow can be recognized as a potential hazard to ground personnel if flown at the same delivery altitude.

CHARACTERISTICS

Capacity	800 Gallons		
Increment	Four 200-Gallon Tanks		
Tanks Released [1]	Evacuation Time (sec)	Av Flow Rate (gallons/sec)	Peak Flow Rate (gallons/sec)
1	1.0	200	350
2	1.1	360	670
4	1.2	670	1000

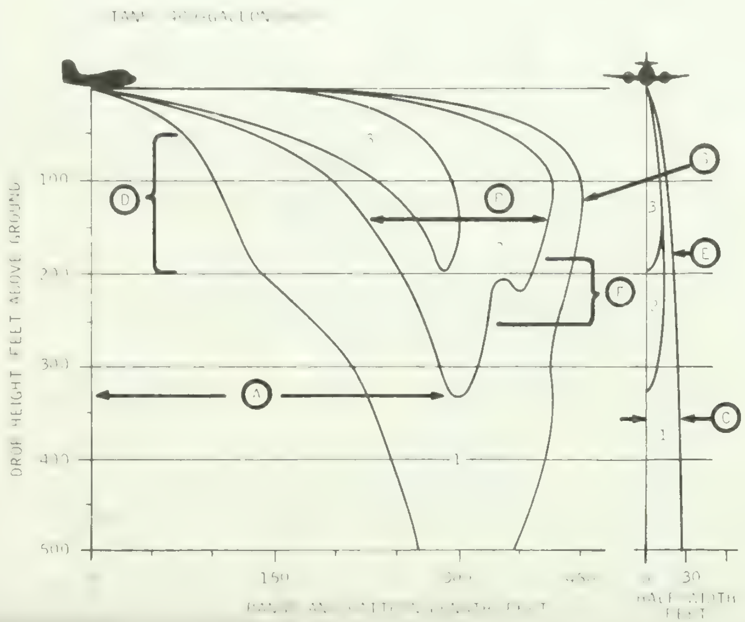
[1] Number of tanks released simultaneously

- Δ Average Flow Rate: An indicator of coverage levels generated in the pattern--the lower the value, the lighter the pattern.

- Δ Peak Flow Rate: An indicator of the pattern's momentum. Values much above 1,000 gallons per second should be considered as potentially dangerous to ground personnel when released at low altitude.

RETARDANT FOOTPRINTS

Retardant footprints indicate aircraft capability at various coverage levels over a range of altitude. Patterns are generated at the mid-range of aircraft speed. The following factors can be determined by examining the footprint:



(A) Approximate distance from point of release to the center of the pattern, the point of highest concentration. This distance is useful in estimating the amount of lead required to place the pattern on spot fires.

(B) The approximate length of pattern at a given coverage level and drop height. This value in association with observed fire response can be used to check or refine the recommended coverage level values in specific fire situations.

(C) The effect of altitude on pattern width. Note in this case the maximum area coverage at 1 occurs around 190 feet where the width is greatest just prior to the reduction in length (E).

(D) Noncritical drop heights. The pattern is relatively insensitive to uncontrolled variables within this range. Small changes of altitude do not cause the pattern to drop below the recommended coverage level.

(F) A critical drop height, where the pattern line (at level 2) falls off rapidly, can become discontinuous, and is sensitive to variables such as wind or drop height.

(G) An indication of the drop height at which the retardant mass loses its forward velocity and falls vertically.

A hypothetical 800-gallon drop (A) was made from the Hemet Valley-S2F using Fire-Trol 100 (B) at an estimated drop height of 200 feet (C).

The line boss estimated that the drop pattern was effective over not more than 150 feet (D).

From the footprint, the coverage level appropriate to the specific fire fuel situation can be estimated as shown at right. By comparing the estimated effective length with the coverage level profiles, we can estimate the minimum useful coverage at about 3 (E).

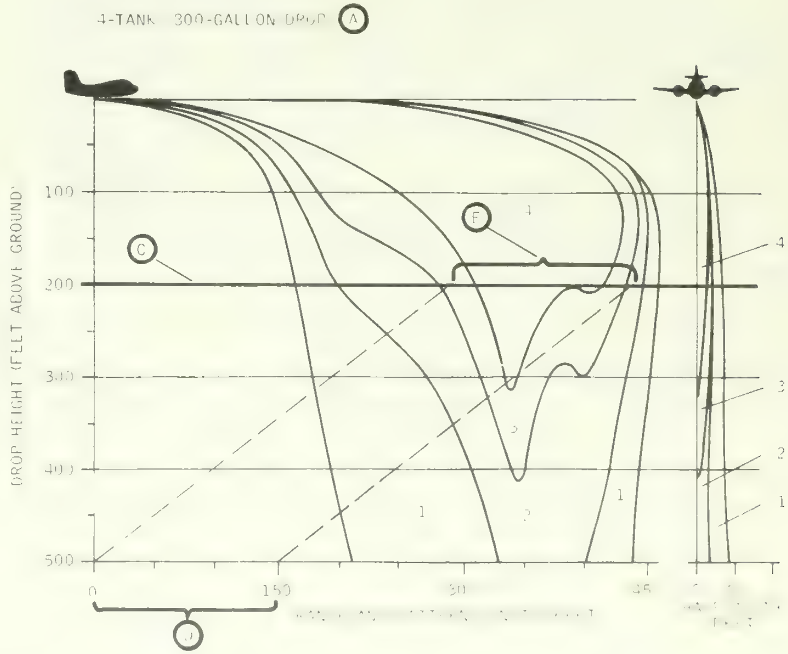
Subsequent evaluation showed the fire was absolutely extinguished for about 50 feet along the flight path.

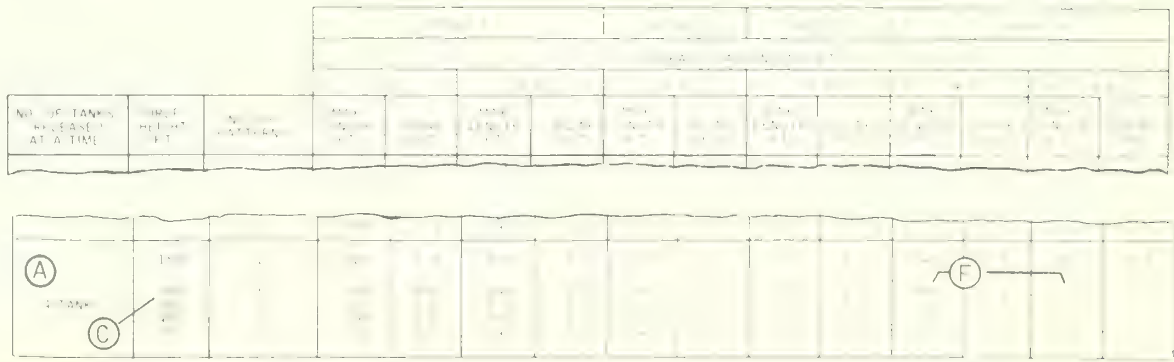
From the Line Length/Opening Delay Tables, the coverage level for extinction can be estimated by examining the estimated lengths at higher coverage associated with the drop (F).

By this process, in association with intelligent experimentation, it is possible to utilize an aircraft with reasonably well-defined drop characteristics to gather important information on the effect of retardants on actual fires. For this reason, drop postmortems and data collection are encouraged.

Pattern Coverage Characteristics - WATERLIKE Retardants

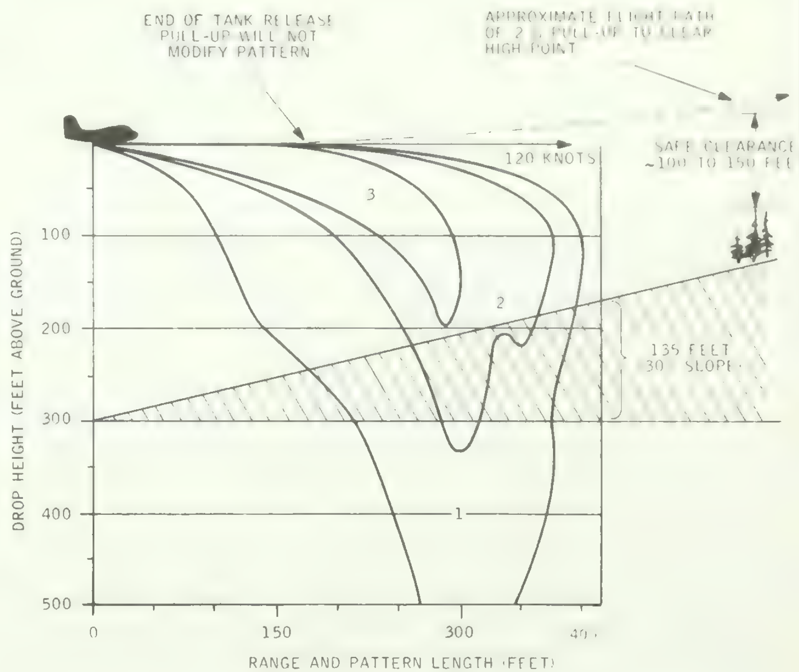
(B) [Fire-Trol 100, Fire-Trol 931 (LC) and Water]





UPSLOPE AND DOWNSLOPE DROPS

The retardant footprints can also be employed to estimate the coverage achievable and approximate release points in terms of altitude and range for drops against severe slopes. In the example at right, a 30% grade is shown as a rise of 135 feet over the 450-foot span of the graph. A straightedge moved across the footprint at the appropriate angle allows assessment of appropriate release strategy or the ground coverage levels developed. With some additional calculations, the capability of the aircraft to accomplish the drop and to escape safely can be examined under various terrain-clearance conditions.



BEST STRATEGY CHARTS

Best Strategy Charts summarize the Line Length/Opening Delay Tables to allow quick identification of the number of tanks and approximate delays between releases that will achieve the most efficient use of the retardant load for any combination of coverage level, line length, and drop height. A key to use accompanies the charts.

The charts illustrate several important points:

First, selection of a coverage level that is too high may produce a large reduction in efficiency, particularly when low levels will suffice. Tanking systems lose flexibility when used to apply excessively heavy coverage.

Second, the Charts show ground personnel and mission planners what can specifically be expected from the aircraft. It allows assessment of whether the use of a full load (dropping maximum line), higher coverages, or multiple drops are more efficient in a given fire attack situation.

Finally, the Charts show the limits of accuracy and safety of ground personnel in direct-attack or close-support operations.

in the operations. This will be GUM-THICKENED (such as Phos-Chek) or WATERLIKE (such as Fire-Trol 100).

(B) Select the chart for the appropriate coverage level for fuel and fire situations in the area of operations.

[illegible]	[illegible]	DESCRIPTION
1	[illegible]	GRA[illegible], TUNDRA, AND [illegible]EN DESERT SHRUBLANDS
[illegible]	[illegible]	[illegible] TIMBER WITH GRA[illegible] UNDERSTORY [illegible] WITH MU[illegible]H GREEN MATERIAL
[illegible]	D	[illegible] FEET IN HEIGHT (SUCH AS SAGEBRUSH)
	E	HARDWOOD LITTER AFTER LEAF DROP
	H	CLOSED CONIFER TIMBER WITH LITTER ONLY
[illegible]	[illegible]	HARD CHAPARRAL AND OTHER HIGH (6-FOOT) FLAMMABLE SHRUBS
	[illegible]	CLOSED, OLD CONIFER TIMBER WITH LITTER AND DEAD, DOWN LIMB WOOD
	I	[illegible]

[illegible] COVERAGE LEVEL [illegible]

(C) Estimate the length of line required for a particular drop at the selected coverage level.

(D) Determine drop-height limits: (1) to assure aircraft safety in clearance of terrain features both before and after the planned release and (2) to protect ground personnel in close-support operations.

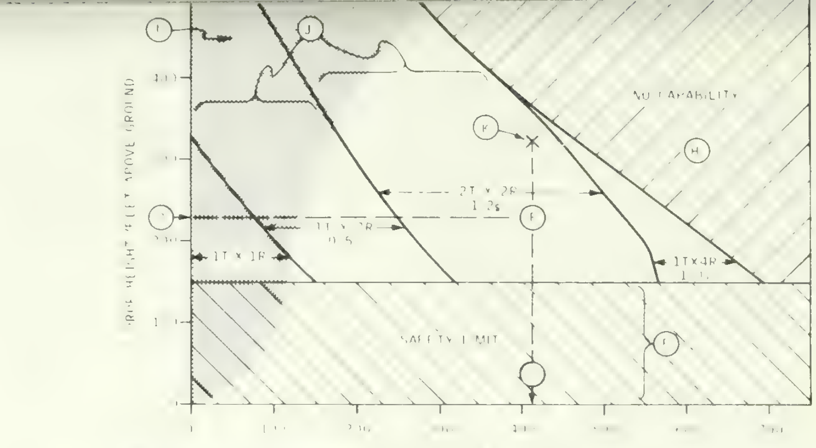
(E) Identify the region on the chart defined by the line-length, drop-height condition. This will identify the best release strategy to achieve the required coverage:

$$\frac{2T \times 2R}{1.2s}$$

The number of tanks to be released at one time

The number of successive releases

The approximate interval between releases in seconds



(G) NOTE [illegible] 200 300 feet

(F) SAFETY LIMIT--Usually expressed as a fuel clearance distance; will normally be at 150 feet above ground or greater depending on terrain or fuel features.

(G) NOTES--Indicate altitude limits for high-momentum drops potentially dangerous to ground personnel when used in close support or call out other recommendations or limitations for a particular strategy.

(H) LIMITS OF CAPABILITY--The aircraft cannot produce, in a single pass, line length greater than that defined by the limit curve.

(I) REGION OF LIMITED ACCURACY--The ability to place a pattern of the specified coverage level on a spot fire is doubtful if operations must be conducted in this region.

(J) OPERATING REGIONS--Most efficient use of the available retardant and pattern controls will occur for the strategy listed. For more precise intervalometer settings see the detailed tables.

(K) If the desired drop is well within the linebuilding capability of the release strategy, consider flying higher. This will result in a wider pattern and increase safety.

MAXIMUM LINE LENGTH TANK OPENING DELAY TABLES

The Maximum Line Length tables show, for a selected altitude, the proper delay between tank releases to achieve the maximum coverage over a range of potentially desirable coverage levels.

A The number of tanks released simultaneously is the basic building block of the pattern. Thus, the value 2 indicates a two-tank salvo. The number of patterns B tells how many salvos are delivered. The column entries tell the maximum length of line that can be achieved with reasonable certainty at any coverage level, as well as the correct interval setting C between salvo releases to achieve that value. These delays are far more precise than those presented in the Best Strategy Charts.

Note that intermediate values can be estimated, if desired, by interpolation between points listed.

A		B	LEVEL 1				LEVEL 2		LEVEL 3		LEVEL 4			
			COVERAGE (GALLONS 100 FT²)											
			0.5		1.0		2.0		3.0		4.0		6.0	
NO. OF TANKS RELEASED AT A TIME	DROP HEIGHT (FT)	NO. OF PATTERNS	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC) C	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
	150	1	275	0.0	140	0.0					-		-	--
		2	565	1.5	330	1.0	145	0.1	35	0.0	—	-	-	-
		4	1145	1.5	710	1.0	395	0.7	230	0.0	145	0.2	35	0.0

COMPARISON OF RETARDANT CAPABILITIES

All data in the guidelines are presented for two different retardant formulations. The distinction is based on the type of thickening agent, which controls retardant breakup and survival as it falls. The two retardants are:

- Δ Gum-thickened--including Phos-Chek XA, Gelgard, and Gum-Thickened Fire-Trol 931 (LC)
- Δ Waterlike--including Fire-Trol 100, Fire-Trol 931 (LC), and water

The two categories refer to rheological properties that influence the breakup in the airstream, not fuel-coating or fire-control capabilities, which appear to be similar.

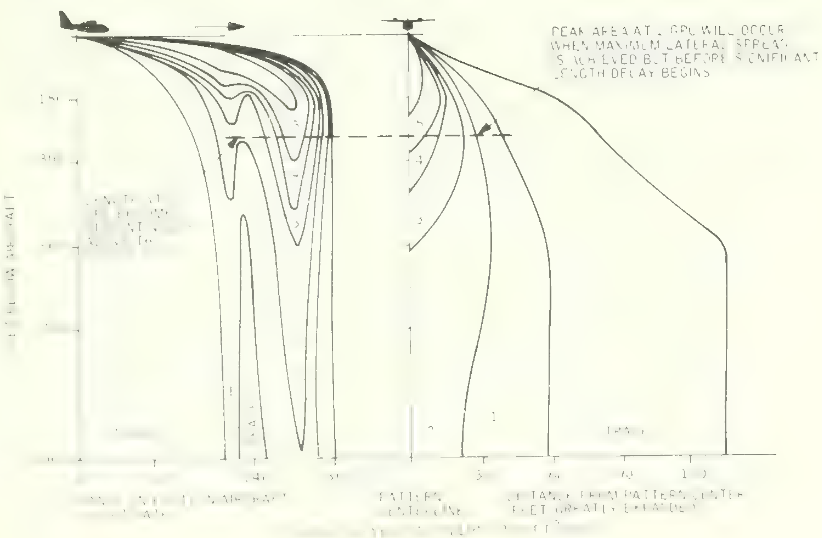
The advantage of the gum-thickened retardant is its tendency to break into larger droplets that provide less surface to evaporate and a higher drop momentum that resists wind deflection. This is shown by comparing the pattern footprints on the following two pages.

That the two types of retardant are equivalent in other respects is supported by the following evidence:

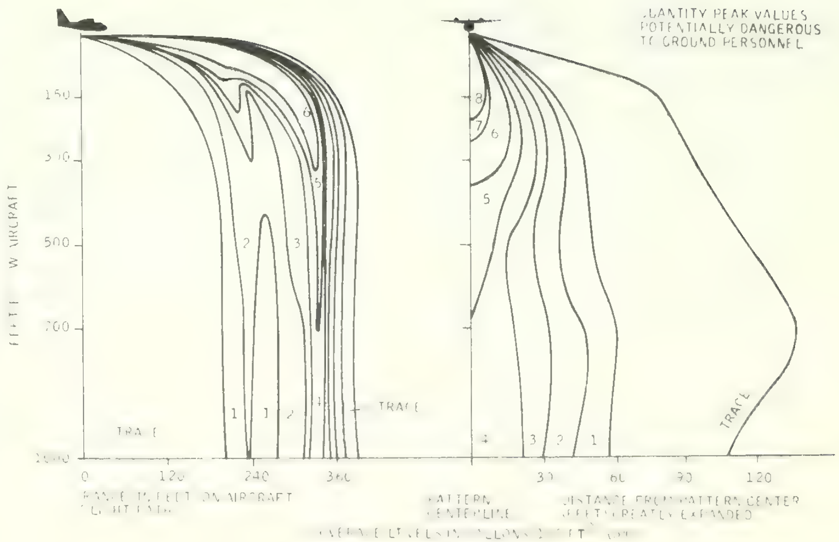
gum-thickened retardants in dip tests (static conditions), they appear to produce thinner coatings when splashed against the fuel surface (dynamic conditions). Because both conditions contribute to actual fuel coating, the differences might well be offsetting. Observations in the field tend to support this contention in that it is difficult to identify retardant compositions by fuel coverage in areas of similar concentration.

Δ Retardant Effects on the Fire: The active salts of commonly used retardants produce differing effects on certain fires. In terms of effect on spread rates, which is critical to most air-delivery missions, the salt concentration is set to produce equivalent effectiveness. Differences are so minor that a single value of Maximum Useful Concentration applies to both commonly used retardants. (Rothermel, R. C., and C. W. Philpot, "Reducing fire spread in wildland fuels," Northern Forest Fire Laboratory, Missoula, Mont. July 9, 1974).

The accompanying graphs show altitude survival for various coverage levels in a single-tank drop of waterlike retardant. The graphs indicate length of line at any given coverage level. Note that pattern width increases as the retardant falls, until the processes of pattern decay (evaporation losses and overspread) begin to offset the advantages of increasing width. This process yields maximum area coverage at delivery altitudes that are often higher than the lowest safe delivery. In this case the maximum area above 2 gallons per 100 square feet would be expected to occur at about 250 feet.



Phos-Chek XA exhibits the altitude performance conditions shown in the accompanying graphs. The pattern retains its coherency over a far greater altitude range than for waterlike retardants. This is caused by the formation of larger, more uniform drops that reduce evaporation and diffusion losses as the pattern spreads. In this example, the pattern width reaches a peak at around 250 feet, which also corresponds to the maximum length value.



NOTES ON PATTERN PLACEMENT ACCURACY

To be effective, a retardant pattern must land where we want it. Some landmark must serve as a target. Some targets are precisely defined--such as the smoke or flame of a spot fire or fuels stained by a prior retardant drop. Other targets are not specific, but are general objectives--the right flank of the fire, for example. In this case, some arbitrary aimpoint must be assumed as the reference for placing the drop. The position of the aimpoint is not the only uncertainty in pattern placement. Others include:

A. Systematic Uncertainties

- Groundspeed
- Altitude
- Aiming error
- Pilot reaction time
- True line of flight

B. Tank and Retardant Uncertainties

- Trajectory variability
- Ballistic errors
- Wind
- Equipment response time

Values of these uncertainties, taken from known data or estimates, are tabulated in an error budget.

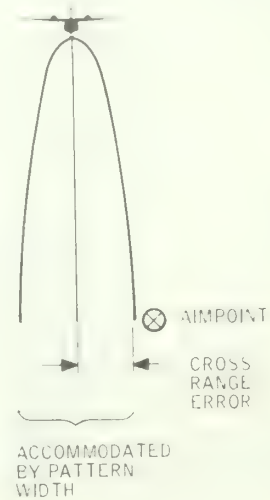
These uncertainties result in two kinds of inaccuracy:

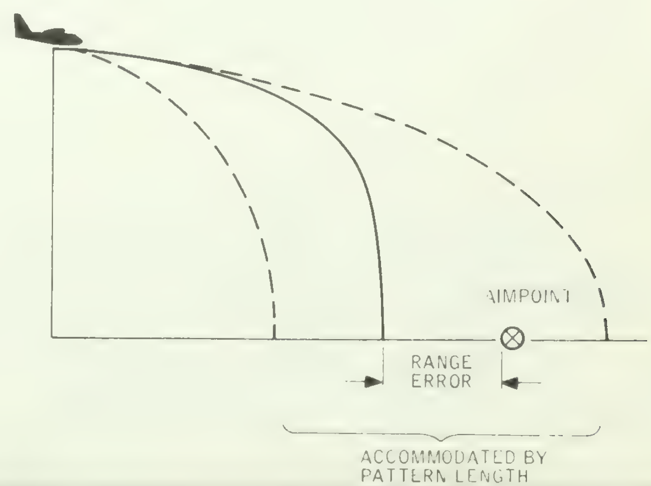
1. Range Errors--Related to the time of release and aircraft position with respect to the aimpoint along the flight path. It is the distance the pattern lands up- or down-range from the aimpoint.

2. Cross-Range Errors--Related to the distance the pattern lands left or right of the aimpoint.

<u>Range Errors</u> are the most common accuracy problem. Range errors are also easily overcome by generating long patterns.

<u>Cross-Range Errors</u> are smaller than range errors, but we can do little to correct them by manipulation of tanking options. Although the width of the pattern generally increases with altitude, it does not increase as fast



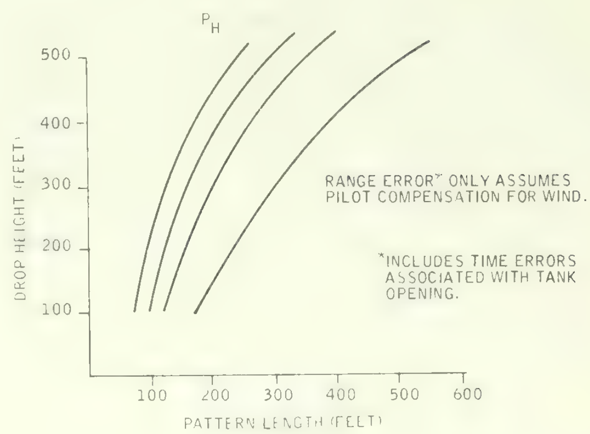


related to the drop. Therefore it is not practical to give explicit guidelines on accurate delivery. Aircraft tanking systems can be used to accommodate range errors by increasing line length proportionately. The pilot begins his drop early and prolongs the release to insure hitting the intended aimpoint.

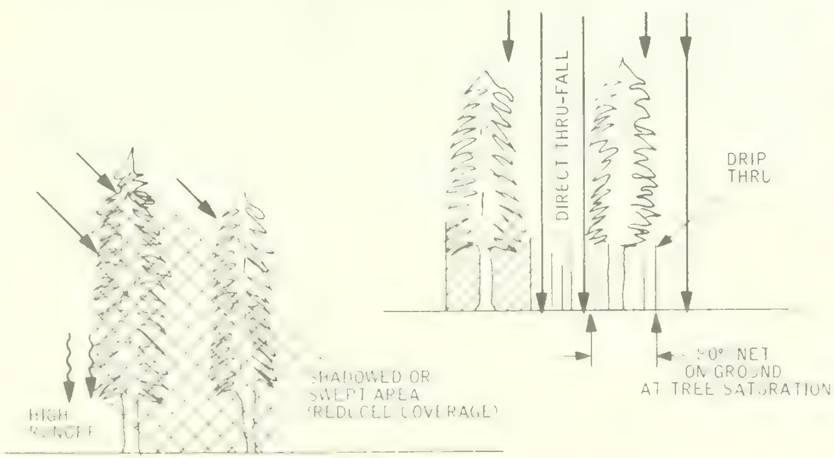
The right-hand figure shows how line length affects probability of hit (PH) under good (low-wind) delivery conditions. A probability of hit of 60 percent is used on the Best Strategy Charts to define regions of limited accuracy.

Accuracy can be enhanced as follows. Whenever possible, fly so that uncertainties are predominantly those of range, which can be overcome by increasing line length. Fly with the wind (or against it), not cross-wind. Second, build the longest continuous line at adequate coverage level from a single aircraft pass rather than attempt to connect patterns from separate deliveries. Third, use similar retardant and drop missions repeatedly, allowing the pilot to develop experience in judging his drop trajectory.

PROBABILITY OF HIT (%)
(ONLY RANGE COMPONENT OF ERROR CONSIDERED)



NOTES ON COVERAGE OF GROUND FUELS



Flight options for adequately covering fuels beneath an overstory are:

A Delivery in horizontal flight from relatively high altitudes which takes advantage of the vertical openness of most stands.

A Attempts to drive the retardant through the overstory by low-level or dive attack.

Near-vertical fall of the retardant usually yields the most uniform and consequently most efficient retardant distribution, particularly in open areas. The overstory shields certain areas as the angle of entry is increased. Drip-through prolongs the application time (about 10 minutes) which can be a benefit.

U.S. GOVERNMENT PRINTING OFFICE 1976 ... REGION NO. 8

Swanson, D. H., C. W. George, and A. D. Luedecke
1976. Air tanker performance guides: general instruction manual. USDA For. Serv. Gen. Tech. Rep. INT-27, 19 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

A method for determining air tanker performance through static testing and a basic format for user guides has been developed which will allow more flexible and efficient use of air tankers. The detailed instructions outline how to read and use air tanker performance guides containing general information, retardant coverage requirements, pattern footprints, best strategy charts, and detailed line length tables.
OXFORD: 432.3, 843.1
KEYWORDS: air tankers, performance guides, fire retardant chemicals, aerial fire suppression, recommended coverage level.

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AMERICAN REVOLUTION BICENTENNIAL 1776-1976

GROWING FROM '76

NTENSIVE FIBER UTILIZATION AND PRESCRIBED FIRE:

EFFECTS ON THE MICROBIAL ECOLOGY OF FORESTS

A.E. Harvey,
M.F. Jurgensen,
M.J. Larsen

USDA Forest Service General Technical Report INT-28
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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PREFACE

National projections show substantial increases in the demand for wood and wood fiber-based products, especially housing materials. Environmental considerations favor extending the use of wood, a renewable resource that can be processed with less energy and less pollution than alternative materials. Present utilization standards and logging practices leave large amounts of residue--small trees, cull and broken logs, tops, and dead timber--on the ground following harvesting. These residues can contribute to the forest's nutrient reservoir, reduce erosion, protect seedlings, improve soil quality (by either natural decay or as a fuel for natural wildfire) and provide wildlife cover. However, in the quantities that frequently occur, residues can also create an unnaturally high fire hazard, inhibit regeneration, detract from esthetic values, and waste scarce fiber resources.

Interactions between logging systems, silvicultural treatments (such as prescribed fire), and their respective residues will be manifested by changes in the soil microflora. These contributions are controlled by the basic physical and chemical aspects of the forest environment that are influenced by man's activities in the forests. Results of these activities will affect the nature and function of both individual and collective microbial populations. Microbial activities will be mediated primarily through changes in the soil which may have a subsequent effect on site quality.

Presently, little is known about the optimum amount and kinds of residue needed to maintain or improve soil quality after timber is harvested. This compendium was prepared as a basis for initiating research into the microbiological effects of alternative residues management procedures and to bring about an awareness of the potential problems and opportunities in this arena of environmental manipulation.

Past research reports many instances wherein management actions have had unforeseen effects on soil quality. This reflects a lack of knowledge of many forest environments and emphasizes the need to examine each forest condition individually. Only by better understanding the net effects wrought by management practices on each forest environment, can its soil be protected as a storehouse of essential microbial activity, mineral nutrients, and physical characteristics, which together comprise the substrate for growth of future forests.

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ABSTRACT

Reviews current knowledge of the effects of intensive wood utilization, prescribed burning, or a combination of both treatments, on the microbial ecology of forest soils. Identifies additional research that must be done to fill voids in knowledge.

THE EFFECTS OF INTENSIVE UTILIZATION AND FIRE ON SITE QUALITY

Intensive Utilization

Soils are developed by the integrated action of environmental forces upon parent erials. The soils produced have physical, chemical, and biological properties that ive from the relative influence of parent materials, climate, living organisms, ography, and time.

As forest soils mature, their properties become more distinct and more stable. highly characteristic properties of forest soils are dependent on the presence of anic material on the soil surface, the continuous or periodic additions of fresh erial as litterfall, and decaying woody materials. To the extent that it changes rate of deposition and decay of organic material deposited on the forest floor, lization may alter the rate or direction of soil formation processes.

When organic materials are removed from a site, such as by logging, the release unavailable nutrients in soil is accelerated (Borman and others 1968). Likens and ers (1969) demonstrated that severe treatments of watersheds result in the increase nitrates and other mineral anions in streamflow. European experience has also wn that continuous litter and residue removal inhibits growth[1] (Krause and Hartel 5; Weidemann 1934, 1935; Albert 1924). Close utilization of residues has not been espread in North America. However, in certain loblolly pine stands in eastern yland where leaf litter had been regularly removed as a bedding material for animals, e (1925) reported a decrease of both height growth and volume. In Quebec, Weetman Webbar (1972) indicated that on dry sites with low organic reserves, whole tree ging may deplete nutrients during the second rotation. Zinke and Colwell (1972) ee, and indicate that only stems and trunks should be removed during harvesting. iage, branches, and roots should be left as an organic resource.

Decaying woody materials contribute to the desirable properties of forest soils persist for decades (McFee and Stone 1966). Further, decaying woody material stitutes the primary food base for a myriad of decay fungi that may serve as nutri- sinks that reduce losses from leaching of mineral nutrients (Stark 1972). Thus, oval of the organic material may reduce soil nutrients that require many decades to onstitute, naturally or otherwise.

Even on favorable sites with stable soils, changes in organic resources could have rt-term effects. For instance, any treatment that alters the relative ability of ifers and brush species to compete during recovery stages could affect early cessional development. Whether or not such changes are desirable depends on manage- t objectives.

Clearcutting has great impact on residue reduction and soil disturbance. Clear- ting temporarily interrupts the cycling of nutrients between the plants and the soil it increases both soil temperatures (Day and Duffy 1963) and moisture (Bethlahmy 2). Those changes favor decomposition of residues and other processes that increase rient release to the soil (Likens and others 1969). Removal of the plant cover also errupts evapotranspiration and increases water movement through the soil system

[1]Lesniká Práce. 1933. Damages caused by removal of forest litter. Vol. 12:137-146.

(Bethlahmy 1962; Coltharp 1960), increasing the probability of nutrient loss through leaching. However, most forest soils have a high capacity to retain nutrients against ground and surface runoff (Fredrickson 1972; Cole and Gessel 1965). If revegetation occurs rapidly, within a few years systems characteristic of the area are reestablish (Marks and Borman 1972).

The amount and distribution of slash and the extent of disturbance to the forest floor and soil systems are strongly influenced by the method of clearcutting (Bell and others 1974). Under some circumstances, even extensive thinning can cause site damage (Tamm 1969). Similarly, whole tree utilization may cause small losses of nutrients that could be significant after many harvest removals (Boyle and others 1973; White 1974). The needles and twigs contain a large proportion of the nutrients of the tree (Boyle and others 1973; Keays 1970, 1971). Thus, the combined effect of clearcutting, logging method, and intensive or whole tree utilization may have significant impacts on site quality. These impacts and the ability of specific sites to withstand them remain to be determined.

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Fire

The main ecological effect of fire is to compress the oxidative activities of ecay into a very short time span. Most of the products of either biological or heat xidation are similar in chemical composition and in quantity (Hall 1972; Komarek 970). With the exception of charcoal, fire residues are eventually consumed by icrobes as they would be in biological decomposition. Charcoal residues are not only ighly resistant to decomposition, they also change the soil environment (Tyron 1948). harcoal has been known to persist in soils for several hundred years (Soper 1919). hus, fire or the lack of fire can have longstanding effects on forest soils.

Fires in heavy fuels can sterilize and change the biological, physical, and chemical haracteristics of the upper soil horizons (Neal and others 1965). Changes include ncreasing soil pH from 0.3 to 1.2 units widening the C:N ratios of soil organic atter, and reducing soil pore size, aeration, water-holding capacity (Ralston and atchel 1971; Neal and others 1965), and water infiltration rates (DeBano and Rice 973). These changes usually reduce microbial activities for varying periods after he burn (Ahlgren and Ahlgren 1965; Wright and Tarrant 1957). Reinoculation occurs rom windblown spores or other debris, and through invasion from subsurface layers. ecause burning changes the soil's physical and chemical properties and eliminates any potential competitors, microbes adapted to the changed soil environment have an dvantage in the recolonization process.

When moisture is sufficient, the microbial population is quickly reconstituted, rimarily from organisms adapted to the new soil environment. The reconstituted opulation may be greater and more active than the original one (Ahlgren and Ahlgren 965), perhaps because of the large quantity of mineral nutrients released from the sh and because of other shifts in soil chemistry. For example, spores of the root athogen *Rhizina undulata* Fr. germinate only after exposure to elevated temperatures Gremmen 1971). It thereby gains access to soils that are rich in nutrients, that are ikely to contain young and susceptible conifer roots, that harbor few competing rganisms, and that have low concentrations of heat-labile growth inhibitors (Watson nd Ford 1972). Increases in other potential conifer root pathogens have also been eported after burning (Wright and Bollen 1961; Tarrant 1956).

Temporary reductions in conifer-fungal mycorrhizal consociations have been found after burning (Wright 1971, 1958; Mikola and others 1964; Wright and Tarrant 1957; Tarrant 1956). Experimental heat sterilization of soils stimulates the production of biologically degradable phytotoxins (Rovira and Bowen 1966). Creation of such toxins by surface fires and their subsequent microbiological breakdown may represent important processes in forest soils. Mycorrhizal fungi have been reported to neutralize the effects of such toxins (Zak 1971). These changes will vary in degree and duration, depending on the intensity of the burn, soil type, climatic characteristics, and the type of vegetation that becomes established after the burn.

Most soil nitrogen (N) is present in the form of nitrogenous compounds contained in leaves, small twigs, and other materials of the decaying duff. Both laboratory (Knight 1966) and field studies (Metz and others 1961) have established that substantial net losses of N occur due to burning. However, N and other mineral nutrients in specific residue materials can increase. The apparent activity of micro-organisms active in the N cycle is increased in postburn soils (Jorgensen and Wells 1971; Neal and others 1965). Although net losses of N occur through volatilization and leaching, increases in N-fixing organisms of many soils may reconstitute a portion of this loss (Metz and others 1961; Wells 1971). Thus, the extent of N fixation and subsequent soil N transformations occurring after fire are critical factors in evaluating the long-term effects on site quality.

Although fire can have many detrimental effects on the soil environment, frequent burning on stable soils does not significantly damage site quality (Stone 1971; Wells 1971). Further, most forested ecosystems in North America have evolved under the direct influence of fire (Habeck and Mutch 1973; Komarek 1962; Ahlgren and Ahlgren 1960). In north temperate forests energy is stored at rates that exceed natural utili zation (Olsen 1963). Therefore, fire or silvicultural alternatives may be required to maintain site quality by freeing energy and nutrients bound in forest residues. Not yet defined are the limits and conditions under which the rejuvenative (Lyons and Pengelly 1970: Kamarek 1962) and protective silvicultural benefits (Davis 1959) provi by fire exceed its potential for damage.

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RELATIONSHIP OF UTILIZATION INTENSITY AND FIRE TO MICROBIAL ECOLOGY

The major microbial functions in a forest ecosystem are carried out in the soil environment. The surface layers of a forest soil may contain 10 to 100 million bacteri and 1 to 100 thousand fungi per gram (0.035 oz). The microbial mass in the top 6 inche (15.2 cm) of an acre of fertile agricultural soil has been estimated at 1,000 lb (450 k of bacterial and 2,000 lb (900 kg) of fungal biomass, on a dry weight basis (Bollen 1959). Soil, litter, and woody residue, largely in the form of cellulose and lignin, constitute the energy base for this intensely active component of a forest. The minera nutrients required to maintain a forest ecosystem are largely derived from such residue and the microbial activity it supports.

Plant nutrients are derived directly from the atmosphere or soil parent materials mainly through microbial metabolism. The accumulation of organic materials in or on forest soils provides not only the energy source for microbial growth, but also a rese voir for available nutrients. Thus, a forested ecosystem is characterized by a large, highly efficient, internal circulation system that transfers mineral nutrients between the plant cover and the soil. Production of large quantities of biomass from forest soils is the result of this system (Ovington 1962).

How forest residues contribute to the soil resource, through natural decay or pre scribed fire, must be understood and managed if extreme changes in soil properties are to be avoided. The soil is a dynamic system that is maintained by an unstable equilibrium of physical, chemical, and biological processes. Residue effects are mediated primarily through changes in soil parameters, e.g., temperature, moisture, aeration, acidity, nutrient and energy supply, and available biota (Bollen 1974). It is appropri ate to examine in detail how close utilization or burning of residues affects the six factors directly involved in this delicate equilibrium.

Temperature

Each micro-organism has an optimum temperature both for growth and for each of m metabolic processes that contribute to its ecological functions. Outside these tempe ture optima, growth or function ceases or changes (Raney 1965). Within any given for micro-organism populations are comprised primarily of those well adapted to the preva ing temperature regime. Radical changes in soil temperatures, such as those resultin from clearcutting, particularly when associated with residue removal or burning, can engender radical changes in microbial populations (Parr 1968). These fluctuations ar most pronounced in the uppermost soil layers where temperatures are strongly influenc by radiation exchange or short-term effects of burning. The success of the subsequen forest depends upon this layer.

Moisture

The optimum moisture content of forest soils for microbial activity is near 50 percent of its water-holding capacity (Bollen 1974). As moisture decreases below tha level, growth and metabolism of the soil microflora are reduced. When soil becomes air-dry, both processes essentially cease. On the other hand, as moisture increases, the air supply is reduced (displaced). As air displacement increases beyond 50 perce microbial growth and metabolism are again reduced, until all aerobic processes come t a near standstill (Stolzy and Van Gundy 1968). Treatment of forest residues profoun

affects buffering of soil moisture extremes, particularly the rapidity of drying of upper soil layers during the summer (Day 1963; Day and Duffy 1963). Drying rate is also strongly affected by climate and site. For example, residues in wet spots remain saturated for most of the year and decompose very slowly; and soil moisture loss in the summer will be more critical to the microbial activity of a southwest-facing slope than of a north-facing slope.

Aeration

Gaseous oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2) are components of the atmosphere vital to microbial metabolism. Oxygen is required for most processes that decompose carbon compounds, to produce energy for growth. Most micro-organisms require at least a trace of CO_2 to initiate growth. This compound is also an end product of energy-related metabolism. Excessive amounts of CO_2 can retard microbial activity (Wimpenny 1969). Certain N-fixing organisms incorporate gaseous nitrogen directly into cellular constituents. Thus, movement of atmospheric gases into the soil must be adequate for satisfactory exchange. Any residue treatments that impede ventilation will predictably reduce microbial activity by restricting O_2 supplies or by permitting gases to reach toxic concentrations (Clark and Kemper 1967). Treatments that encourage compaction or the formation of impermeable soil layers can be exceedingly detrimental. Accumulation of organic soil residue does not adversely affect the gas exchange process.

Hydrogen Ion Concentration (pH)

Concentration of hydrogen ions in the soil strongly affects microbial activity. The observed effects of soil acidity on micro-organisms may be attributed to (1) changes in organic matter availability; (2) pH-caused nutrient deficiencies; (3) toxic effects of hydrogen or aluminum ions; or (4) a combination of the above factors (Jurgensen 1973). Micro-organisms differ in their degree of tolerance to pH change. Some thrive only in a very narrow range and others tolerate wide extremes (Davey and Danielson 1968).

Radical changes in soil pH result from the effects of residue management, especially fire (Wells 1971). The presence of ash or charcoal increases basicity. When such a change occurs, organisms with either a wide pH range or a narrow pH range suitable to the new regime replace the previously existing biota. This effect is particularly pronounced as soil pH nears neutrality and the acid-base activities approach balanced levels. Thus, the microbiological activities of weakly acid forest soils are highly susceptible to drastic change.

Forest soils are typically acid. Leaching increases acidity through loss of mineral elements. The extent and rate of nutrient loss is a function of cation exchange capacity in areas of sufficient rainfall. Partially decomposed residues provide an important source of exchange sites, particularly in coarse-textured soils.

Nutrient and Energy Supply

Because most soil organisms are heterotrophic, they require a source of energy in the form of carbon compounds. The effect of forest litter and woody residues on soil microbial activity depends on the type of material, its nutrient content, and on the initial fertility of the soil (Davey and Danielson 1968; Waksman and Tenney 1928). A lack of suitable organic substrates normally limits the growth of heterotrophic micro-organisms in soil (Gray and Williams 1971).

Although an abundance of carbon (C) compounds is desirable, excessive amounts can produce marked expansion of microbial populations and excessive competition for mineral nutrients. Soil micro-organisms require many of the same nutrient elements as do

higher plants and can, at times, provide intense competition to plants for these nutrients. Because of the low N supply in most woody residues and other similar materials, competition generally results in severe N deficiencies termed "immobilization" (Zoettl 1965). The immobilized N is used in the production of microbial cells and, although it is not lost to the site, it is unavailable to higher plants until death and decomposition of the microbes exceed their population growth (Mulder and others 1969). For an optimum rate of decomposition, the C to N ratio should approximate 25:1. In decay-resistant woody residues, the ratio is much wider (approximately 400:1), but much of this C is in the form of lignins, which break down slowly (Allison and others 1963). Thus, lignicolous materials exert low but long-term N demands. Humus, and therefore most soils, should have a narrow C-to-N ratio (approximately 20:1)

Humus is mostly made up of highly decomposed material. The material that is not decomposed is highly resistant to further breakdown. Humus also contains a large quantity of the available cation exchange capacity for nutrient storage. Mineralized soil N is easily released from these cation exchange sites and is readily available for plant or microbial growth. N deficiencies in humus normally occur only when high C-to-N ratio, readily decomposible residues become incorporated. This begins a rapid decay process that quickly immobilizes much of the soil N supplies (Bartholomew 1965). On the other hand, residues that remain on but not in the soil may, through slow decay, actually increase N supplies to the soil under the right conditions.

Available Biota

Soil organisms compete for mineral nutrients, food supplies, and possibly oxygen (Clark 1969), which leads to highly refined competitive mechanisms adapted for specialized niches. Production of antibiotics, and parasitism, predation, and symbiosis serve as examples. Competition sometimes limits the development of certain species and leads to successions of organisms as decomposition proceeds (Alexander 1964).

Frequently, the nature of the microbial successions is dictated by the pioneer organisms present when a food source becomes available. Pioneer organisms are largely controlled by the previously described physical and chemical parameters that govern macrohabitat. Pioneer species may impose permanent changes on the subsequent successions of micro-organisms until a specific food source is exhausted (Shigo and Ellis 1973). Residues and residue treatments directly influence the successional patterns. Thus, the pioneer organisms prevalent during the season in which the residues are generated may control subsequent microbial populations.

As indicated previously, available moisture, temperature, and amount and kind of organic substrate dictate the type of organisms active in the soil at any given time. Biotic history can also influence soil microflora. For example, previous activity of soil pathogens or stem decays may affect reforestation. Residues indirectly affect soil activity just as they affect the establishment of higher plants on the site, e.g the establishment of *Alnus* or *Ceanothus* species following burning provides host roots for certain symbiotic organisms (Youngberg and Wollum 1970). Similarly, specific conifers are hosts for certain ectomycorrhizal fungi.

The roots of pioneering plants directly influence the soil. The soil area surrounding the roots of higher plants, termed the rhizosphere, is characterized by very intense microbial activity. This activity is based on leakage or sloughing of food materials, such as certain sugars and amino acids, from the roots (Rovira 1969; Slankis and others 1964). The extent and influence of such root systems in soils are little appreciated. A single rye plant grown in 2 ft^3 (0.06 m^3) of soil had 13,800,C roots with a total length of 387 mi (619.2 km), and 14 by 10^9 root hairs with a total length of 6,600 mi (10,619 km), and provided a total surface area of 6,874 ft^2 (638.6 The total external surface of the shoots and leaves of this plant provided only 51.38 ft^2 (4.72 m^2) of surface area (Ditmer 1937). A 55-year-old Douglas-fir is reported

to have 464 ft ($141.4 m^2$) of roots greater than 1 cm in diameter (McMinn 1963), but the greatest length and surface area would be contributed by smaller roots. Dead roots are also important as food supplies for decay organisms in deep soil strata.

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IMPACT OF RESIDUE MANAGEMENT PRACTICES ON CRITICAL MICROBIAL ACTIVITIES

Of the many important activities of soil micro-organisms likely to be influenced by residue management practices, the following are critical and are considered priority items for research: (1) Recycling of materials bound in woody residues through decomposition and decay; (2) establishment and function of mycorrhizal activities; (3) accumulation and retention of soil N in the forest ecosystem; and (4) activities of indigenous plant pathogens.

Decay

For purposes here, decomposition or decay is defined as the enzymatic oxidation of chemically complex woody plant materials by micro-organisms, predominantly fungi (Satchell 1971), to more simple compounds and nutrients that become part of the soil. These materials make up the nutritional organic base of the forest. Woody materials in the various stages of decay may be at the soil surface or be totally or partially imbedded in it. Tree residues, depending on size, persist up to 150 years or more (McFee and Stone 1966; Dimbelby 1953). In the surface foot of soil, woody residue comprises a significant volume, up to 30 percent (McFee and Stone 1966). Hence decomposing woody tissues are an important component of the organic-containing soil layers in temperate forests. As integral parts of the soil system and function, their impact is yet to be fully elucidated.

The Role of Residue Decay in the Forest Ecosystem

The decay and decomposition of plant materials have long been the subject of papers and discussions in both forestry and agriculture. The Carbon Cycle is particularly important to both disciplines. This is the process by which C is photochemically fixed, assimilated by the plant and, after its death, reduced to a variety of simple organic compounds and CO_2 by the soil microflora (fig. 1). The left side of figure 1 encompasses the processes involved in CO_2 fixation by tree growth, the right side depicts CO_2 release through decomposition associated with fungi and other micro-organisms. The decomposition of plant materials in a forest is one of the more complex phenomena associated with this cycle.

In any ecosystem, there is a balance between fixed and decomposed carbon. The principal controlling factors in this cycle are:

1. Light
2. Temperature
3. Moisture and Moisture Regimes
4. Latitude, Slope, and Aspect (insolation)

Restrictive limitations imposed by any one of these factors normally result in responses from the plant community that are reflected in the rate of biomass production and its decomposition (Loman 1965, 1962; Olson 1963; Spaulding 1929a, 1929b).

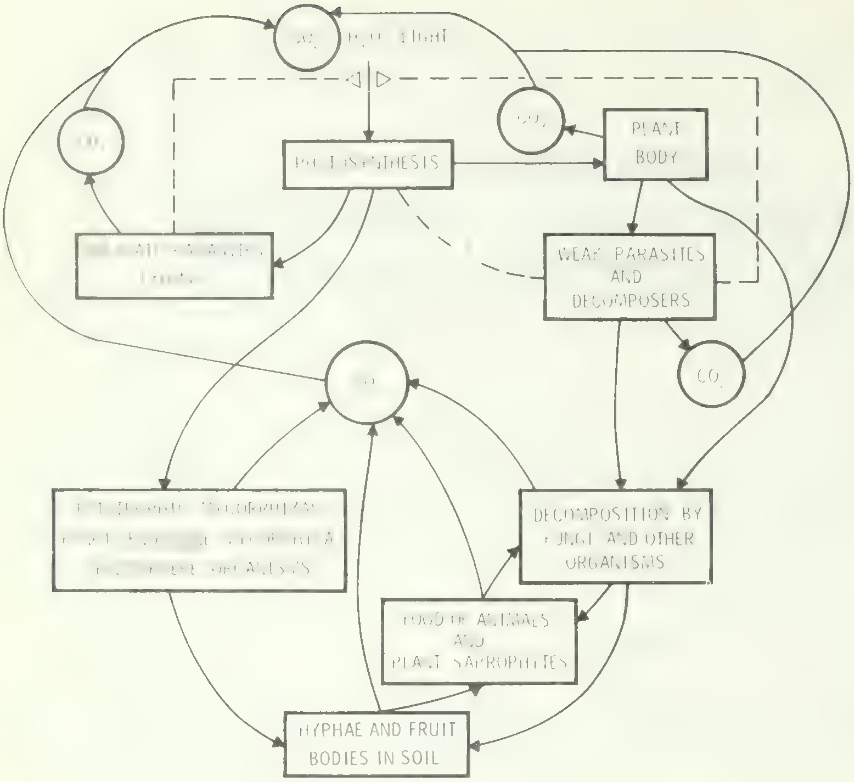

Figure 1.--The role of fungi in cycling carbon within an ecosystem. On the left is the symbiotic cycle directl using photosynthetic products. The decomposition cycle is shown on the right (after Harley 1971).

When examining the C cycles of forest trees and agricultural crops, the major differences between the two are readily apparent. Agricultural practice usually involv annual harvest and site management (with appropriate mineral and organic fertilizer amendments). In forest practice, harvest occurs between 80 to 150 years (sawtimber) or 15 to 25 years (pulpwood) and site management related to fertility and production of th new crop is left primarily to natural processes. Man's interference with these processes has been restricted to (1) limited forest fertilization, (2) nursery-grown outplants, (3) broadcast seeding (often with rodent control), and (4) silvicultural practice that may change forest type.

Man's most recent intercession in the natural events of forest regeneration and stand development (in addition to previous and existing timber harvesting and manageme practices) has been the removal of both natural and manmade forest residues--a practic stimulated by increased needs for wood fiber (Foulger and Harris 1972; Gardner and Hann 1972). These practices have generated questions regarding the effects of residue removal on fungal populations as they relate to mycorrhizal and disease activity, and nutrient release through decomposition. Survival of conifer seedlings during the initial period of establishment is intimately related to these populations and process Survival becomes especially critical on the drier sites (Day 1963; Day and Duffy 1963)

The Nature of Residue Decay

The form and age of residues influence the rapidity of decay. Residues formed from young materials have a fast turnover rate, under optimum decay conditions, due to their high carbohydrate content (or lower lignin contents). Residues formed from old-growth timber are more resistant to decay (Waksman and Tenney 1928). Polyphenolic material (tannin) derived from lignin or lignin like compounds are a component of fores

soils in the form of residues at various stages of decay. They ultimately control the nature of the organic resource and the nutritional, physical, and biological quality of the soil (Davies 1971). For example, Bollen and Lu (1969) reported that tannins (polyphenols) in bark of Douglas-fir stimulate certain molds in the soil.

Studies on the decomposition of forest litter have been conducted by Adam and Cornforth (1973), Kowal (1969), Daubenmire and Prusso (1963), Witkamp (1966), and Hayes (1965a, b). These workers have dealt primarily with leaves, small twigs, and bark. Allison and Murphy (1963) and Allison (1961) studied the decomposition of wood and bark particles in soil but did not examine whole wood on bark. In most of the above work, the specific fungi associated with the decomposition processes were not indicated. Agrawal (1971), in contrast, did utilize specific litter fungi to assay for cellulytic capacity. His experiments, however, were confined to prepared cellulose which does not lend itself to accurate ecological interpretation.

Wagener and Offord (1972) have presented data on the relationship of time to slash decay in northern California. After 34 years, 43 and 85 percent volume reductions of piled slash were observed in two different experimental areas. Estimates of slash volume decayed over periods of time have also been provided by Toole (1965), Roff and Eades (1959), Gil and Andrews (1956), Kimmey (1955), Spaulding and Hansbrough (1944a, b), Kimmey and Furniss (1943), Childs (1939), Spaulding (1929a, b), Hubert (1920), and Long (1917).

The Function of Residue Decay

In addition to the function of decay as a mineral recycling agent, Seidler and others (1972) have recently suggested that the decomposition of woody tissues in conifer stems of the Pacific Northwest may provide a significant ecological niche for N-fixing bacteria of the genus *Clostridium*. Cornaby and Waide (1973) reported the microbial fixation of atmospheric nitrogen in decaying and decayed logs of *Castanea dentata* in the southeastern United States and presented convincing evidence to support the hypothesis as stated by Cowling and Merrill (1966): the possible dependence on external sources of N to support decay fungi in woody materials. The association of N-fixing organisms with the decay process may be extremely important in two ways: (1) by affecting the rates of decay in forest residues, and (2) by site N-replenishment as affected by kinds and amounts of woody residues.

Another important effect of residues, buried or otherwise, is their moisture-holding capacity (Barr, 1930). Large (log-sized) residues act as perched water tables that may eventually dry out, but at much slower rates than the associated soil or small (litter and branch) residues. Such residues provide, in many cases, well-defined ecological niches in or on which fungi survive and function in an environment otherwise unfavorable to them (Zak 1969).

Decaying residues strongly influence nutrient accumulation through fungal activity and nutrient release (Stark 1973). Stark (1972) has presented data suggesting that fungal hyphae act as "nutrient sinks" by incorporating and binding (concentrating?) essential nutrients into their structures. The fungal soma is eventually decomposed, resulting in slow nutrient release. That fungi are accumulators of substrate nutrients has also been pointed out by Harley (1971).

The Fungi Associated With Residue Decay

Many species of decay fungi have been collected and studied by mycologists and pathologists. These fungi have been detailed as parts of checklists in monographs, or noted as occurring in restrictive ecological niches (Richards 1970). For the most part they have not been related as particular species, or even as broad taxonomic groups, to ecological functions (Hering 1972). The fungi responsible for decomposition are in

themselves complex in genetical, physiological, and ecological makeup. They constitute a group of organisms that are both adaptable and unstable. Their survival, growth, and reproduction may frequently be limited by their ecological requirements. Only recently have investigators attempted to establish more precisely the roles of decay fungi in the forest environment (Aho 1974; Shea 1960). It is not enough to know the fungi present; knowing why they are or are not present under particular forest environments, manmade or otherwise, is equally important.

Conclusions

Processes involved in decomposition are essential aspects of carbon, nitrogen, and mineral cycling, all of which are intimately related. However, present knowledge is fragmentary, particularly when ecologically interrelated processes concerned with residue decay are examined. Tentative conclusions are that continuous cropping and intensive utilization decrease site productivity (Pierovich and Smith 1973; White 1974). In ecologically sensitive areas, residues, as substrates for specific fungi, may have to be managed as intensively as the trees themselves if productivity is to be maintained.

Research Needs

The following questions remain to be answered. How much hetero- and autotrophic plant biomass is a particular site producing? How much does the N economy of a foreste site depend on residue decay and associated micro-organisms? In terms of site maintenance, do more desirable or less desirable populations and species of fungi occur? How does one manage or select for fungal populations and species most beneficial for site maintenance? These complex, interrelated questions reflect the kinds of research that must be done.

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Mycorrhiza Formation

Within the zone influenced by plant roots exists a wide variety of functional associations between roots and certain micro-organisms (Lewis 1973). Perhaps the most specialized of these are the mutualistic (symbiotic) associations, termed mycorrhizae, that occur between the roots of most higher plants and certain fungi. Most participating fungi and their hosts have evolved a strong interdependence for survival in natural ecosystems (Harley 1971, 1969). In mycorrhizal associations, each partner benefits from the other (Trappe and Fogel 1974). This is illustrated by the complete failure of afforestation from seed or seedling in areas where soils lack the appropriate mycorrhizal-forming fungi (Mikola 1973; Vozzo and Hacskaylo 1971; Trappe and Strand 1969) and by the difficulty in culturing the fungi in the absence of the host root (Palmer 1971; Gerdemann 1968). Many fungi form mycorrhizae on one, or only a few species or types, of host plant (Gerdemann and Trappe 1974; Chilvers 1973), so changes in vegetation can result in direct alterations in populations of mycorrhizal fungi. Thus, site treatments that affect populations of mycorrhizal fungi, either directly or through competition, or the ability of these fungi to form the mutualistic association, could create highly significant impacts on growth or regeneration of the succeeding stand.

Mycorrhizal Anatomy and Development

Four major types of mycorrhizae are recognized on the basis of internal and external anatomy. The orchidaceous and ericaceous mycorrhizae are a diverse group of fungi with septate hyphae, normally found on members of the Ericaceae and Orchidaceae. These are characterized by intracellular penetration that ultimately digests the host cells. The vesicular-arbuscular mycorrhizal fungi have nonseptate hyphae and usually occur on members of the Cupressaceae, Taxodiaceae, Aceraceae, some species of the Ericaceae, most herbaceous species, and all woody plants not ectomycorrhizal. These fungi occur on more plant species than any other type. They penetrate the root but form spores external to the root and cause little, if any, change in morphology. The ectomycorrhizal fungi are found on members of the Pinaceae, Fagaceae, Betulaceae, Tiliaceae, and several other minor plant families. The ectomycorrhizae are characterized by a highly specialized morphology and are required for the survival of the Pinaceae and several other woody plant families in temperate ecosystems (Trappe and Fogel, in press; Meyer 1973). The fungi involved are generally higher basidiomycetes or ascomycetes that form a characteristic mantle of fungal tissue completely enclosing the host rootlet. Penetration by the fungus is largely limited to the intercelular regions and only rarely occurs within the cell. Intercellular ramification by the fungi, with the absence of cellular digestion, restults in the formation of a netlike structure, termed the "Hartig net," wherein fungal tissues completely surround the cortical cells. Invasion does not proceed beyond the endodermis (Harley 1969). In some instances, intermediary types (ectendomycorrhizae) are formed and are characteristic of certain species (Zak 1971). The following discussion will emphasize the ecologically obligatory associations between members of the Pinaceae and the ectomycorrhizal fungi because of the direct relationship with regeneration of the important western timber-producing species.

Normally, a young conifer seedling is infected during the first growing season (Robinson 1967). The fungus spreads as a weft of mycelium (fungal strands) over the young roots until the entire surface of the root, including the apex, is covered. Ultimately, a typical thick mantle of fungal tissue is formed. Penetration into the root generally coincides with but can precede the maturation of the mantle. As root systems enlarge, each new crop of roots becomes infected. Infected young rootlets, devoid of root hairs, emerge from the lateral root completely ensheathed by the fungus and are gradually transformed into a characteristic mycorrhizal structure. Young lateral roots become transformed into an easily recognizable series of short, often much branched series of clublike root tips. Branching patterns, colors, and other characteristics are often associated with particular host-fungus combinations (Zak 1971; Wilcox 1968).

Mycorrhizal Physiology

Mycorrhizae are substantially longer lived than nonmycorrhizal roots (Harley 1969; Orlov 1968). In addition, the fungal hyphae function as extensions of the root system, absorbing and translocating soil nutrients and water to the host (Bowen 1973; Harley 1969). They may also act, in concert with other fungi, as nutrient sinks for conservation of nutrients on the site (Stark 1972; Harley 1971).

The fungal symbiont is not generally capable of utilizing complex carbohydrates as an energy source and is, therefore, largely dependent on the host for a supply of simple sugars (Hacskaylo 1973; Harley 1969). During times of extreme drought, the surface soil layers which normally contain the mycorrhizal fungi are most affected and the host may supply both water and nutrients from deep soil horizons (in addition to the energy source) and enable a mycorrhizal partner to survive.

Mycorrhizal Function

Ultimately, mycorrhizal hyphae and structures derived from them can fuse, forming large networks of interconnected fungal bodies, permitting increased absorption and translocation of nutrients between hosts sharing a common fungal network (Furman and Trappe 1971; Reid and Woods 1969). Among trees direct grafting of roots also occurs (Borman 1966; McMinn 1963). Thus the forest soil consists of an interconnected series of pipelines that acquire and share required materials through a highly sophisticated and delicate balance of structures derived from both higher plants and their fungal symbionts. Photosynthate (sugars) and mineral nutrients can be transferred between plants through the various components of this system (Reid and Woods 1969; Borman 1966; Woods and Brock 1964). Of particular significance are the possible increases in uptake and transport of ammonium nitrogen (Melvin and Nilsson 1952), synthesis of amino acids the mycorrhizal structures (Krupa and others 1973), and increased absorption of phosphate (Bieleski 1973; Bowen 1973).

The advantages of an underground pipeline, particularly to plants growing in a harsh and infertile forest soil environment, are readily apparent. Mineral nutrients, water, and even photosynthate may be supplied to new seedlings or to individual trees occupying extremely harsh microsites. An early acquisition of the benefits provided by this soil pipeline is particularly critical to seedling survival. In the absence of mycorrhizae, seedling root penetration below the summer drought zone and root surface area are not adequate to provide sufficient mineral nutrients during the first several seasons in even the most moderate forest soil conditions. Thus, some of the most successful plants that occupy rigorous nondesert sites, such as timberline or coal spo banks, are ectomycorrhizal (Schramm 1966). Fungi adapted to particular environments appear to have evolved concomitantly with the ability of certain plants to survive in extreme environments (Marx and Bryan 1971; Moser 1958). Many species of mycorrhizal fungi associate with only a single genus or even subgenus of host, others are apparent nonspecific (Chilvers 1973; Smith 1971; Trappe 1962, 1971).

The large assemblage of mycorrhizal fungi encompasses a wide spectrum of physiological and ecological capabilities. Potential functional differences between species are expressed in habitat preferences and successional changes in fungi with the age of host and season (Anderson 1966; Mikola 1965; Dominik 1961, 1958). Fungal species have demonstrated differences in resistance to temperature or moisture stress (Mexal a Reid 1973; Hacskaylo and others 1965; Moser 1958), and nitrogen utilization (Bowen 197 Lundeberg 1970). Differential growth responses of vascular plants to different mycorrhizal fungi have frequently been observed (Bowen 1973; Mikola 1973; Laiho 1970). Mycorrhizae can in some instances be pivotal factors controlling plant succession (Robinson 1972; Handley 1963). Nitrogen-fixing organisms may be stimulated by mycorrhizae (Rambelli 1973; Silvester and Bennett 1973).

Mycorrhizal seedlings resist drought better than nonmycorrhizal seedlings (Bowen 973; Shemakhanova 1962). In one case a severed spruce shoot survived for 8 months as result of an intact connection between a mycorrhizal root and the rhizomorph of a ycorrhizal fungus emanating from the soil on which it lay (Simonsberger and Koberg 967). Seedling losses related to desiccation are particularly severe in clearcuts here soil and plant surface temperatures can kill tissues (Day 1963). Limited water upplies make seedlings even more susceptible to heat injury, and resultant losses mpose long delays in restocking cut units (Day 1963; Day and Duffy 1963). Early ormation of mycorrhizal structures may be particularly significant in reducing heat ortality by increasing the seedlings' access to soil moistures.

In summary, contact with specific mycorrhizal networks and soil conditions ppropriate for mycorrhizal establishment are essential to the survival and growth of onifer regeneration (Zerling 1960).

istribution of Mycorrhizal Fungi

Little is known about the distribution and persistence of ectomycorrhizal fungi part from their hosts. As a rule, mycorrhizal fungi do not produce fruiting bodies or porulate in the absence of live host roots (Romell 1938). Survival in the form of aprophytic hyphae in the soil is probably limited (Harley 1969; Gerdemann 1968). yphal aggregations termed rhizomorphs may persist for some time due to their tough uter layers and ability to transport nutrients, but they are probably limited to ithin a few feet of active host roots. Mycorrhizal short roots may survive a short hile after tree harvest due to the tough outer mantle and possible storage of food aterials. However, evidence to support any of the latter contentions is not as et available.

At present, it is generally thought that mycorrhizal fungi do not survive for xtended periods in the absence of host roots (Hacskaylo 1973), and that they reinvade hrough airborne spores (Lamb and Richards 1974) only after the appearance of suitable osts on the site. Thus, clearcutting may drastically reduce the populations of ycorrhizal fungi in direct proportion to the removal of the hosts, particularly onifers. Little or nothing definitive is known concerning spore dispersal patterns nd their germination requirements, or their effectiveness in reestablishing mycorrhizal ungi other than they have been observed to act in some instances as effective inoculum Theodorou and Bowen 1973).

otential Impacts of Residues Management on the Mycorrhizal Association

In addition to the requirement for a suitable host and fungus, the environment in hich the two meet imposes a strong influence on their ability to form a successful ycorrhizal association (Björkman 1970). Thus, the soil factors affected by clearcut- ing and burning cause site changes that could alter mycorrhizal symbiosis.

Temperature directly affects root colonization by mycorrhizal fungi (Bowen and heodorou 1973; Theodorou and Bowen 1971) and their growth in vitro (Harley 1969; acskaylo and others 1965). The related factor of soil moisture can also limit growth f mycorrhizal fungi (Bowen and Theodorou 1973), and in some instances low soil moisture ay be responsible for the replacement of some mycorrhizal fungi by others (Worley and acskaylo 1959). Similarly, soil aeration as related to soil water content has been eported to affect mycorrhiza formation (Mikola 1973; Mikola and Laiho 1962; Heikurainen 955). Soil acidity appears particularly critical in successfully controlling species f mycorrhizal fungi on the site and in the ability of the fungi to form the mycorrhizae Bowen and Theodorou 1973; Theodorou and Bowen 1969; Richards 1961). The complex series f physical, chemical, and biotic changes wrought by forest burning result in temporary eductions in mycorrhizal roots on conifer regeneration (Wright 1971; Mikola and others 964; Wright and Tarrant 1958; Tarrant 1956).

Other more subtle effects of management on the quality of forest soils may control the ability of mycorrhizal fungi and their hosts to form the mycorrhizal association. Availability of nutrients, organic matter, and an energy supply in the form of simple sugars are critical to mycorrhizal fungi. In general, mycorrhiza formation is enhanced when there is a mild deficiency of mineral nutrients (Hesterberg and Jurgensen 1972). Hatch (1937) reported a deficiency of nitrogen, phosphorus, potassium, or calcium stimulated mycorrhizal development. Björkman (1942) found the amount of soil nitrogen and phosphorus to be decisive factors in the formation of the association. He also found that the addition of ash to certain soils increases the numbers of mycorrhizae (Björkman 1941).

Though plants with mycorrhizae can be cultivated in soils with a low organic content (Björkman 1956, 1954), high levels of organic matter are reported to have favorable effects on mycorrhizal development (Rubtov 1964; Rayner 1936, 1938). As a single amendment, organic matter can promote formation of mycorrhizae in deficient soils (Mikola 1973). Forest residue levels would greatly affect the subsequent organic matter content of the soil. Similarly, the presence of decaying roots appears to promote mycorrhiza formation (McMinn 1963).

One of the most notable physiologic characteristics of most mycorrhizal fungi is their requirement for simple sugars as energy sources. Such substances are generally thought to be supplied through plant root exudation (Hacskaylo 1973). Thus, factors that influence sugar levels in the host plant and its transport to and liberation from roots, such as sunlight and mineral nutrition, may affect mycorrhizal development (Björkman 1970).

Stand composition, at the time of harvesting, may condition the soil either favorably or unfavorably for the succeeding crop through the influence of roots and their exudates. Rhizosphere microflora that compete for simple sugars exuded from roots may directly affect mycorrhizal fungi (Harley 1969); antagonistic rhizosphere fungi may have suppressive effects (Levisohn 1957); root pathogens may influence development of mycorrhizae or vice versa (Marx 1973); and certain micro-organisms common in the vicinity of roots may be synergistic to the formation of mycorrhizal structures (Voznyakovskaya and Ryzhkova 1955). Higher plants or lichens may release soil chemicals that trigger allelopathic responses among mycorrhizal fungi (Handley 1963; Wilde 1954; Brown and Mikola 1974). Early succession of shrub species, which are typically vesicular-arbuscular mycorrhizal, may affect the establishment of ectomycorrhizal fungi and therefore their hosts, such as pines (Trappe, personal communication).

Management of temperate forests for optimal tree growth and to favor selected species will also require the management of the fungal symbionts on which these trees depend. Present and contemplated forest residue practices will directly influence the symbiotic mycoflora. Examination of the net effects of these influences will provide valuable information regarding biological impacts of management and may provide direct inputs into management tactics designed to achieve optimal growth of predetermined species.

Research Needs

Before it is possible to assess the environmental impacts of treatments on various sites in forested ecosystems, the following questions that relate mycorrhizal development to intensive utilization and prescribed burning, or to both, must be answered. Does extensive removal or burning of host trees or organic material reduce or change populations of mycorrhizal fungi at specific sites? If so, how quickly and by what means do these populations reconstitute themselves? If effects are significant, do they constitute a hazard to, or delay, the establishment and growth of the succeeding stand?

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Soil Nitrogen Fixation and Transformations

Of the many elements essential for plant growth, nitrogen (N) is required in greater amounts than any other mineral nutrient and has been found to be a limiting factor for tree growth in both eastern and western forest soils (Stone 1973; Heilman 1961). The amounts of N present and its subsequent availability in forest soils depend on a variety of chemical, physical, and biological processes.

Nitrogen values vary from less than 0.02 percent in subsoils to greater than 2.5 percent in organic soils. The average N content in the surface layer of most soils ranges from 0.03 to 0.4 percent; the amount decreases with soil depth (Bremner 1967). Spacial variations in N distribution are especially evident in forest soils where considerably greater amounts of N are found in the litter layer than in the mineral soil (Gessel and others 1973). Estimates of N levels present in the litter beneath western stands have ranged from 80 kg/ha for pinon pine-juniper to over 1,300 kg/ha in second-growth Douglas-fir (Zavitkovski and Newton 1967; Youngberg 1966).

Man, by his intervention in the forest ecosystem, can have a significant impact on the N cycle and consequently on site productivity (Wollum and Davey 1975). Nitrogen is unique among the soil nutrients because it is present in the soil almost entirely as organic forms. No inorganic reserve is normally present to alleviate soil N lost to tree removal, to volatilization, or to leaching (Zoettl 1965). In natural ecosystems the atmosphere supplies N to the soil through the fixation of inert N_2 into forms useful to plants. However, these gains in total N can be balanced by losses through biological conversion of nitrate to the gases N_2 or N_2O (denitrification), removal by timber harvesting or burning, and by leaching into the subsoil (Knight 1966; Norris 1962). Each process in the N cycle is related to site productivity and would be strongly subject to change by forest management practices.

Nitrogen Fixation

Considerable work has been done in attempting to evaluate the relationship of N-fixation (dinitrogen fixation) to the overall soil N balance and to increase the extent of fixation in the soil. However, the significance and contribution of N-fixation in many ecosystems have still not been resolved. Generally, small amounts of N are added to the soil by precipitation (Allison 1965) and absorption of NH_3 from the air by soil and plants (Malo and Purvis 1964). It has been advocated that the slow oxidation of soil organic matter coupled with sunlight fixes sizable portions of N (Dhar 1960). However, few if any other investigators support the latter view. Therefore, most of the N added to the soil is considered to have come from biological fixation.

Symbiotic

Probably the best known symbiotic relationship associated with N fixation is the bacterial genus *Rhizobium* and the root nodule it forms on members of the legume family *Leguminosae*. Leguminous plants, such as soybean, pea, and alfalfa, are part of food and forage production and have been found to add up to 200 kg N/ha/yr to the soil

under proper management (Stewart 1966). However, most work has centered on agricultural systems and, with the exception of black locust (Ike and Stone 1958), very little is known regarding the extent and significance of the *Rhizobium*-like legume association in forest ecosystems (Wollum and Davey 1975). Information is needed on the distribution of legumes in forest stands, and should include the widely distributed herbaceous and shrubby species.

Possibly of greater importance than legumes to the forest ecosystem is the occurrence of nonleguminous but nodulated plants. More than 113 species have been reported to form nodules. Included are the common western plants red alder *Alnus rubra* and snowbush *Ceanothus velutinus* (Youngberg and Wollum 1970). The exact nature of the nodule-forming endophyte has not been determined. Various investigators have isolated *Streptomyces* from surface sterilized roots of several nodule-forming genera (e.g., Wollum and others 1966). However, these actinomycetes did not cause nodulation when grown under sterile culture conditions.

Nonleguminous plants have been found to fix appreciable amounts of N. Laboratory studies have reported fixation rates equivalent to 56 kg/N/ha/yr for *Alnus rugosa*, 15 kg/N/ha/yr for *Hippophae rhamnoides*, and 4 kg/N/ha/yr for *Myrica cerifera* (Akkermans 1971; Silver and Mague 1970). Considerably higher values have been reported from field studies on snowbush and red alder (VanCleve and others 1971; Youngberg and Wollum 1970; Newton and others 1968).

Certain lichens are another example of a symbiotic N-fixing relationship; in this case, between blue-green algae and fungi. A number of species have been found to fix N both in the laboratory and in the field (Henriksson and Simu 1971; Fogg and Stewart 1968). The actual contributions of lichens to the soil N supply would depend on weather, soil properties, and extent of lichen cover. A study on various volcanic and arid soils found 2 to 4 times greater amounts of N associated with lichen crusts than with the bare soil surface (Shields 1957). Fixation rates from 10 to 100 kg/N/ha/yr have been attributed to lichens in desert soils of Utah (Rhychert and Skujins 1974). The occurrence and development of lichens on certain forest sites have been investigated (Pike and others 1972), but the significance of these organisms to the forest N balance is unknown.

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In contrast to symbiotic N-fixation, the importance of free-living N-fixing micro-organisms in soil is still uncertain. It is generally conceded that the nonsymbiotic N-fixing microflora contribute only small amounts of N to arable soils (Jensen 1965; Henzell and Norris 1962). However, in noncultivated soils such as grasslands and forests where organic matter is not removed from the site, N gains may be significant (Moore 1966). Studies on soil N accumulation and cycling on forested sites have indicated substantial gains of N. In temperate zones, annual N additions have been reported to range from 4 kg/ha/yr in young stands to between 10 and 25 kg/ha/yr in mature stands (Richards and Voigt 1965), although considerably higher values may be obtained on certain sites (Richards 1964). Tropical rain forests appear to have a much higher fixation rate, likely averaging over 50 kg/ha/yr (Greenland and Kowal 1960). Recent soil studies using direct measurement techniques in the field have indicated far lower fixation rates, averaging in the order of 1 to 10 kg/ha/yr (Hardy and others 1973).

This anomaly between the extent of N gains on forest sites and the measurement of nonsymbiotic N fixation in soil may be in part explained by the enhanced microbial activity in the rhizosphere. N-fixing micro-organisms would be stimulated by the generally low N content of organic materials secreted and sloughed off by plant roots (Starkey 1958). Nitrogen gains occurring in this narrow zone around the root would not normally be measured in studies on soil N-fixation. Recent investigations have shown considerably higher N fixation rates associated with the rhizosphere of conifer roots

than with root-free soil (Richards 1973; Silvester and Bennett 1973). Similar stimulation of N-fixation has been reported in the rhizosphere of various grasses, corn, and rice (Dommergues and others 1973; Yoshida and Ancajas 1973). Some investigators have indicated that N-fixing micro-organisms are favored in the rhizosphere of mycorrhizae, as compared to nonmycorrhizal roots (Rambelli 1973; Silvester and Bennett 1973). However, the reduced rhizosphere fixation rates associated with slash pine mycorrhizae (Richards 1973) show that this aspect of nonsymbiotic N-fixation must be studied further.

Another source of N in forest systems may be the leaf surface of plants or "phyllosphere." Ruinen (1956, 1965) isolated N-fixing organisms from the leaves of numerous plant species and showed that leaf exudates were suitable substrates for their development. Various species of *Azotobacter* have been found in the phyllosphere of over 50 species of trees, crops, ornamentals, and aquatic plants (Iswaran and others 1973). Vlassak and others (1973) have isolated blue-green algae from phyllosphere samples of *Ceratodon purpureus*. The algae showed appreciable N-fixing capabilities. In studies on the tropical grass *Tripsacum laxum*, less than 1 kg/N/ha to 3.5 kg/N/ha have been attributed to phyllosphere fixation (Bessems 1973; Ruinen 1970). In a similar laboratory study, Jones (1970) attempted to determine the extent of N-fixation occurring on the leaves of Douglas-fir where he isolated nitrogen-fixing bacteria. Jones concluded that as much as 65 g/ha/day of N could be fixed in some Douglas-fir stands. Although such N gains under natural conditions would appear unlikely, this source of added N to forest sites could be of importance.

In the past, the ability of micro-organisms to grow on so-called "N-free" media was considered proof of N-fixing capacity. However, growth on these media is not positive proof because small amounts of fixed N are always present, and ammonia can be absorbed from the air. Although the incorporation of 15_N is the most definitive method by which N-fixation is established, the acetylene reduction technique is now normally used for field investigations. Many studies have shown that micro-organisms able to fix N also have the ability to reduce acetylene to ethylene (e.g., Hardy and others 1973). Production of ethylene from acetylene is almost completely restricted to N-fixing organisms, and is considered presumptive evidence for the occurrence of N-fixation. Because of its sensitivity, ease in measurement, and economy (Hardy and others 1968), the acetylene reduction technique is preferred over the 15_N analysis.

Numerous genera of bacteria and blue-green algae have been found to contain species or strains having an N-fixing ability. Various fungi and yeasts have also been reported to fix N, although more recent evidence indicates that N fixation does not occur in these groups (Postgate 1971). Several of the nonsymbiotic N-fixing micro-organisms, such as *Azotobacter* and the blue-green algae, are normally restricted to nearly neutral or alkaline soils. However, many others, particularly the spore-forming anaerobes, are so widely distributed that a lack of N-fixing microflora would not likely be a factor limiting N-fixation in forest soils (Jurgensen and Davey 1970).

Mineralization

Nearly all of the N in soil is tied up as organic complexes which, with the possible exception of a few amino acids, are not available for plant uptake. The N must first undergo biological transformation by various components of the soil microflora to be eventually released as ammonium, an N form readily used by plants. This release, or "mineralization" of organic N, together with N present in precipitation, fulfill the N requirements of the plant community (Wollum and Davey 1975).

Nitrogen mineralization is generally determined by the factors that influence decomposition of organic matter, such as kind of organic material, soil moisture, nutrient levels, and the soil macro- and microflora (Bartholomew 1965; Witkamp and van der Drift 1961). Species variation has been linked to changes in decomposition rates of forest tree litter (Witkamp 1966). Mineralization rates generally are the

highest at soil moisture levels near field capacity (Stanford and Epstein 1974). Ammonium production decreases at higher moisture tensions but still occurs even when the soils are below the permanent wilting point (Miller and Johnson 1964). A similar reduction in N release is observed in wet and poorly drained soils (Tusneem and Patrick 1971). Soil chemical properties are significant because the application of fertilizer and lime can cause large increases in mineralization rates (Williams 1972; Broadbent 1965).

Nitrification

Nitrification, the conversion of ammonium to nitrate by soil micro-organisms, has recently been receiving considerable attention because of increased awareness of the role of nitrates in stream, lake, and ground water pollution. In contrast to the positively charged ammonium ion, the nitrate anion is not tightly held on soil exchange sites and is readily leached through the soil profile. Differences in the uptake or "preference" of trees for ammonium vs. nitrate have also been found (Krajina and others 1973; van den Driessche 1971), thus making soil nitrification a factor in developing and evaluating forest fertilization programs.

The bulk of nitrate produced in soils is generally assumed to come from the activity of a select group of autotrophic bacteria, particularly *Nitrosomonas* and *Nitrobacter*. These organisms obtain their energy solely from the oxidation of N compounds. The levels of soil organic matter have little or no direct effect on nitrifying bacteria because they use carbon dioxide as a carbon source (Wallace and Nicholas 1969). However, organic matter indirectly affects nitrification by influencing soil moisture levels, soil temperature, and cation exchange capacity. Nitrifying organisms are much more sensitive to variations in the soil environment than micro-organisms active in mineralization. Nitrification is drastically reduced at low soil moisture levels and under acid soil conditions (Siefert 1970; Merrill and Dawson 1967; Reichman and others 1966).

The Relationship of Residues Management to Nitrogen Transformations

The type and levels of wood residue affected by various management practices greatly influence the development of the soil microflora, especially those active in the N-cycle. Increased residue utilization and prescribed burning would reduce the amount of organic material incorporated into the soil. Because many diverse micro-organisms function in the cycling of soil N, such reductions in residue could have many ramifications. In order to fully evaluate the possible significance of residue practices on soil N transformation, all aspects of the N-cycle must be considered.

Nitrogen Fixation

The impact of forest management practices on the incidence and activity of symbiotic N-fixing associations deserves study, particularly the less conspicuous symbiotic plants. Opening of the forest canopy, either through harvesting or fire, and the resultant change in soil chemical and physical properties could favor or restrict the development and efficiency of an N-fixing flora (Loneragan 1972; Nutman 1972). In either case, the potential of such changes should be considered.

Most of the N-fixing micro-organisms, other than the blue-green algae and the anaerobic phototrophic bacteria, require a supply of organic carbon as an energy source. Adequate energy sources would seem particularly important for these organisms because they are inefficient users of carbohydrates (Stewart 1969). The relationship of soil organic matter to N fixation depends on the type of material, its nutrient content, and on the initial fertility of the soil (Rice and others 1967). Thus, the removal of organic matter from the site by logging or residue utilization could affect the

activity of nonsymbiotic N-fixers in soil or in woody residue. This may be accomplished by reducing the organic sources available to these organisms or by changing the physical and chemical environment of the soil (Jurgensen 1973).

The breakdown and decay of woody tissue could also influence the forest ecosystem by directly affecting N-fixation. The N content of wood/unit carbon is lower than most other types of plant tissue. However, in spite of these low levels of N, wood-destroying fungi are able to metabolize the carbon-rich substrate and produce sporocarps and large numbers of spores comparatively rich in N (Merrill and Cowling 1966). One possible explanation for this phenomenon is fungal use of N produced by N-fixing organisms present in the wood. The N-fixing population could use simple sugars produced by the fungal breakdown of wood and in return, supply N to the primary decomposers. The possibility of such a synergistic relationship was strengthened by the recent study of Cornaby and Waide (1973) who showed low but significant amounts of N were being fixed in decaying chestnut logs. Seidler and others (1972) and Aho and others (1974) have found that a sizable fraction of bacteria isolated from decay zones in white fir had an N-fixing capability. Knutson (1973) has observed that bacteria isolated from healthy and water-soaked aspen were able to grow on N-free media.

Reductions in residue levels by fire would have far different consequences on N-transformations than wood removal through logging. As noted earlier, studies conducted in the Southeast over a 20-year period have shown no significant loss of N from the soil due to prescribed burning; in fact, soil N increases of 23 kg/N/ha/yr associated with annual burning on some sites have been reported (Jorgensen and Wells 1971). Other investigations have also reported increases in the soil N content upon burning (e.g., Klemmedson and others 1962). These N gains have been attributed to an increased legume component in the ground vegetation after fire (Stone 1971). Another possibility is the greater activity of nonsymbiotic N-fixers, particularly the autotrophic blue-green algae. The increased light and nutrient levels of the soil surface as a result of burning would favor the development of such organisms (Jurgensen and Davey 1968).

Mineralization

The mineralization of N from soil organic matter can be altered by forest management practices. Harvesting, fire, and site preparation techniques have all been shown to accelerate the release of organic N (DeBell and Ralston 1970; Likens and others 1970; Neal and others 1965). This is due, at least in part, to the resultant changes of microclimate on the soil microflora (Borman and others 1968). The release of nutrients and pH increase after burning or logging may also favor the organisms responsible for N mineralization. Much of the ammonium released may be immobilized in the breakdown of woody materials. Additional N will enter the soil and become available for uptake by trees. However, some may be leached below the root zone or lost through overland flow if the topography is steep (DeByle and Packer 1972).

Nitrification

Effects of forestry practices on soil nitrification rates and the nitrate content of water supplies are now being questioned. Likens and others (1970) showed that clearcutting and herbiciding of northern hardwoods in New Hampshire greatly increased the soil populations of nitrifying bacteria and, consequently, the levels of nitrate in neighboring watersheds. However, the loss of nitrate after clearcutting has been found to be much lower in other parts of the country (Reinhart 1973). These differences seem to be related to soil type, with podzols being especially susceptible to nitrate losses.

Burning of logging residues has resulted in large increases in soil ammonium levels (Christensen 1973; Neal and others 1965), which may increase soil nitrification rates. The rise in soil pH after a fire would also favor the nitrifying bacteria.

Vegetational changes following harvesting or fire may affect the levels of soil nitrate. The nitrate content of soils supporting red alder is considerably greater than soil under western conifers (Trappe 1972). This species difference may be related to the tannin contents of tree bark and its effect on nitrification (Bollen and Lu 1969). Plant species invading a forest site after disturbance have been associated with nitrification rates higher than rates in climax ecosystems (Rice and Pancholy 1972).

Nitrification is an inevitable process occurring in mildly acid to alkaline soils. Although there has been considerable interest in suppressing the nitrifying bacteria by applying chemicals (Parr 1973), these treatments, even if successful, would likely be limited to relatively small areas of particular environmental concern. Increases in nitrification will generally occur after harvesting or site treatment operations, and due to the nature of the nitrate ion, will result in increased N loss from the soil. The effect of N loss on site productivity depends on the amount of N lost, initial soil fertility, and the extent of N gains coming from N-fixation.

Conclusions

Nitrogen is subject to various biological transformations, many of which occur simultaneously in the soil. Any natural or man-induced changes in the physical and chemical properties of a forest site will greatly affect the activity of the responsibl soil micro-organisms. It is important to understand the impact forest management techniques and objectives have on these processes. By investigating the N cycle and the organisms active in its functioning, problem areas can be identified and resolved by appropriate management and silvicultural action.

Research Needs

Of particular interest are the sources of N-fixation in forest soils and their contribution to the soil N status. The importance of this information for evaluating the nutrient changes in soil and water systems has been stressed (Reinhart 1973). The effects of harvesting, fire, and residue removal on rates of N-fixation, N-release from soil organic matter, and nitrification need to be known. Also required is the effect of the vegetational changes occurring after site disturbance on N transformations and if increased residue removal will significantly alter the N balance in forest soils, especially on steep terrain. Such information will be required to evaluate the potential long-term impact of intensive forestry operations on site productivity.

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Pathogen Activity

Forest diseases have been referred to as negative influences in the forest environment (Boyce 1961; Hubert 1931). However, in terms of productivity and stabilization over many generations, many diseases may prove useful to natural forest ecosystems, particularly in north temperate forests where organic matter is generally produced at a higher rate than it can be recycled through the process of decay (Olsen 1963).

Possible Ecological Functions of Pathogens

It is generally thought that overmature forests are more prone to fiber-destroying disease, particularly stem decays, than young vigorous forests (Boyce 1961). As more and more of a site's raw materials become tied up in plant bodies, the plants occupying that site become less thrifty and more prone to insect and disease attack. This condition will eventually lead to an ecosystem whose productivity, in terms of usable fiber production and game habitat, may be extremely low. Other aspects of productivity, for example, watershed protection, may not be greatly impaired. As dead plant bodies (fuel) accumulate, they become subject to fires during dry seasons. Eventually, insect and disease attacks, in coordination with dry seasons and lightning storms, provide conditions in which wildfires are the primary means of rejuvenating the system (Lyons and Pengelly 1970; Komarek 1963). Under natural conditions this process (cycle) is repeated frequently.

Disease "losses," as traditionally viewed by foresters and pathologists, may be natural site characteristics similar to sunlight, moisture, and other factors. In at least one case, a stem decay has been cited as an agent that may help to preserve a forest climax timber type, the California redwood (Stone and others 1972). In this case, stem decay contributes to stem breakage during high winds which in turn prevents uprooting, thus stimulating root sprout regeneration. Excess losses, however, can be interpreted as a biotic indicator that site rejuvenation is required or an inappropriate stand composition must be changed in order to maintain stability.

Introduced pathogens, such as white pine blister rust, are notable exceptions to a system within which endemic diseases may serve a natural function. Imported disease interrupt natural flow of energy by creating fire-conducive conditions in unnatural circumstances. Harvesting activities, when not conducted within the framework of the natural ecosystem, may also serve to interfere with natural site development to create biotic problems. Management should complement the flow of the ecosystem and could improve the efficiency of natural processes.

By removing resistant hosts from the proximity of heavily infected stands, fire may have changed the genetic evolution of hosts and parasites in fire-dominated forests. The accumulation of resistance, normally associated with delicately balanced host-parasite coevolution, may have been prevented through elimination of the best source of genes to provide resistance. Thus, resistant individuals, due to their close proximity to heavy fuels (dead or dying neighbors), have a high likelihood of destruction by wildfire. Such an explanation has been suggested for the lack of resistance to certain dwarf mistletoes (Roth 1966). Certainly, the relative efficienc of wildfire sanitation has been a major factor in limiting dwarf mistletoes in some situations and dispersing them in others (Alexander and Hawksworth 1975). Other diseases, particularly of the aerial parts of forest trees, have probably been constrained to varying degrees (Chapman 1927), depending on their dispersal capability. As a recycling agent in the forest ecosystem, disease may be so important that internal mechanisms have developed to discourage the incorporation of resistance genes in host populations. This would assure a continuing role for pathogens. The apparent lack of effective resistance to many forest diseases may, therefore, be a direct result of natural wildfire.

As management becomes more intensive and utilization replaces or moderates some o the effects of fire in many aspects of the energy cycling of forests, perhaps the eradicative effect of wildfire on resistant genotypes can be reversed. Considerable benefit may be available through permitting resistance to diseases to be incorporated into the gene pools of forest plants. This could be done through management of fuels by prescribed fire and increased utilization in concert with selection of leave trees, planting stock, or both.

Fire as a Dispersing Agent

Although wildfire is mainly an agent of sanitation, its varying intensities sometimes creates discontinuous effects. Several generations (cycles) of fire may be required to fully cover a forest ecosystem. On a more localized and time-limited basis, particularly in areas with relatively low fire frequency and discontinuous spread, increases in the intensity and losses from diseases can result.

Fire frequency varies with specific conditions and is characteristic of the site (Habeck and Mutch 1973). Presumably, site, species, and fire frequencies have evolved so as to balance the ecosystem at the maximum production level consistent with stability. Although a specific stand may not be optimally productive or stable, the ecosystem is. When fire occurs, it acts as a natural sanitizing and rejuvenating agent (Muller 1929; Weir 1923), which serves to balance energy flow. In the natural state, this system provides a heterogeneous forest of highly mixed ages and species (Habeck and Mutch 1973), a situation that can be considered ideal with respect to minimizing most disease losses. Conversely, fire exclusion over a long period, or devastating fires over large areas, produce a situation analogous to agricultural monoculture: large expanses of frequently overstocked single-age forests with limited numbers of species. This situation is ideal for maximizing spread and intensity of most diseases (Day 1955).

Fire scars represent a major natural infection court for many root and butt rot fungi (Hepting and Shigo 1972; Toole 1959; Nordin 1958; Basham 1957; Toole and Furnival 1957; Burns 1955; Gustafson 1946; Garren 1941; Hepting 1941; Hart 1938; Stickel and Marco 1936; Hepting and Hedgecock 1935; Kaufert 1933; Nelson and others 1933; McCarthy 1928; Schmitz and Jackson 1927; Lachmund 1923, 1921; Boyce 1921), and at least a significant one for several stem canker fungi (Haig 1938; Dearness and Hansbrough 1934). Incomplete postfire removal of dwarf mistletoe-infected overstory creates a situation ideal for the spread and intensification of damage from the mistletoe parasites (Alexander and Hawksworth 1975). Wildfire also contributes to increased disease problems by creating thick stands in which intense competition for space, moisture, and nutrients weakens trees. Such a stand is an ideal substrate for root and stem decay fungi (Baxter 1967; Boyce 1961).

Diseases, like dwarf mistletoe, whose distribution and intensity are directly dependent on fire history (Alexander and Hawksworth 1975), should gradually be eliminated through improved harvesting practices. The effects of most other endemic pathogens can be minimized by controlling stand age, vigor, composition, and inoculum. They probably have been reduced through the sanitizing effect of natural wildfire (Heinselman 1971; Chapman 1927).

Past Efforts of Disease Control Through Use of Fire

The effectiveness of prescribed fire and removal of residues as a sanitizing treatment for disease is widely recognized and has provided the impetus for a number of both successful and unsuccessful attempts to control forest pathogens. In Michigan, attempts to eradicate the sweetfern blister rust (*Cronartium comptoniae*) by burning the infected pines and the alternate host were unsuccessful (Baxter 1967). In the late 1940's, prescribed burning to control the fusiform rust (*Cronartium fusiforme*) in the southern United States failed (Siggers 1949). In the latter case, inoculum was reduced, but counterbalancing epidemiological factors were sufficient to offset the gain. Inoculum reduction and lowered disease incidence were achieved by fire in the southeast, and in India with the brown-spot needle disease (*Scirrhia acicola*) and *Septoria pini* of longleaf pine (Siggers 1944, 1932; Gibson 1938; Chapman 1927).

In many sections of the country, fire is associated with an increase in *Ribes* populations (Davis and Klehm 1939) that support white pine blister rust, and an increase in oaks that serve as alternate hosts for the fusiform rust in the southeast. The spread and intensification of *Nectria* and *Cytospora* canker (Haig 1938; Dearness and Hansbrough 1934) and modification of several other fungal diseases have been associated with burning (Muller 1929). The use of prescribed fire appears well suited as an agent useful for the control of dwarf mistletoe under certain site conditions (Alexander and Hawksworth 1975). Weir (1923) observed that broadcast burning reduced growth and fruiting of the most important cull-producing fungi in Idaho and Montana. He noted that charred stumps and logs are rarely reinfected by the cull fungi of the living tree. Boyce (1961) observed that charring of stumps in the Southwest controlled fruiting of cull-producing fungi, and Roth (1956, 1943) reported reductions in defect of fire-thinned oak when compared to normally harvested or thinned stands. Many of the above cited effects of fire could be duplicated by clearcutting and intensive utilization.

Residue as a Dispersing Agent

Whether related to biotic forces, physical forces such as high winds and wildfires, or to man's activities, plant residues left in place can pose disease problems. Cull-causing decay fungi produce spores from fruiting structures that develop on stumps of fallen trees and other woody residue (Gill and Andrews 1956; Spaulding 1934; Wright 1934; Hubert 1920). Many root diseases are dependent on stumps and roots in the soil or decaying tree butts in contact with the forest floor (Boyce 1961; Kaarik and Rennerfelt 1957). These residues act as a substrate for growth and sporulation and provide the inoculum for new infections.

No other class of forest diseases causes more timber damage than root decays (Nelson and Harvey 1974). The saprophytic stages of these fungi are completely dependent on woody residue to survive from one generation of host plants to the next. Thus, residues may enable the intensification of root disease in proportion to their volume and suitability for colonization by increasing the probability of survival of the causal fungi (Hudson 1968). *Armillaria mellea, Poria weirii,* and *Fomes annosus* are important examples of this type of pathogen. Heart-rotting fungi can also be propagated in this manner (Hudson 1968; Meredith 1960). However, standing dead or live defective trees are probably more important as a source of inoculum for heart-rot fungi. Diseases that attack foliage, and then produce spores on dead and fallen needles, may also represent residue hazards. *Lophodermium, Herpotrichium,* and *Neopeckia* are representative genera (Hepting 1971; Hudson 1968; Boyce 1961).

Survival of pathogens on residue depends on many factors: (1) size and species of residue; (2) charring; (3) soil physical and chemical characteristics; (4) site; (5) host trees available; (6) relative location of residues to the soil and host plants; (7) species of pathogenic fungi present; (8) relative vigor of the hosts; and (9) the adaptive capacities of the pathogens and their potential hosts. Through adequate reduction of forest residues, intensive utilization and fire can suppress many types of diseases. Conversely, allowing residues to accumulate can encourage these same diseases.

Residual Effects of Fire and Harvesting on Site Factors That Influence Disease Problems

In addition to the sanitation influence provided by physical removal of wood or burning, the six macroenvironmental parameters that change as a result of these treatments (temperature, moisture, aeration, acidity, nutrient and energy supply, and available biota) also provide direct influences on disease organisms on, in, or associated with soil components. For example, survival and distribution of cull-producing fungi in slash can be directly influenced by temperatures brought about by exposure to insolation (Loman 1965, 1962).

Soil temperatures of 60° to 70° C for 10 minutes are normally sufficient to kill most root pathogens (Johnson 1946). Surface fires may cause temperatures in this range within the upper 4 inches of forest soils (Van Wagner 1970; Beadle 1940; Raymond Shearer, personal communication). Therefore, substantial reductions in the numbers of certain feeder root pathogens in these shallow soil layers (2 to 4 inches) may occur. However, the reported reduction in fungal and bacterial populations induced by surface fire (Neal and others 1965) and possible concomitant heat or nutrient-induced elimination of soil fungistasis[2] (Watson and Ford 1972, Dobbs and others 1960) could lead to increases in any pathogenic organisms surviving in these soil layers. Pathogens could be introduced on or in the seed (Bloomberg 1966). Increased nutrient availability and reduced competition can contribute to soil colonization advantages by surviving feeder root pathogens and may lead to the fire related buildup of these pathogens (Hartley and Pierce 1917). In addition, the suppressive effects of heat and fire generated soil extracts on soil fungi have been reported to be greater on fungi normally antagonistic to feeder root pathogens than on the pathogens (Widden and Parkinson 1975; Bollen 1969).

The potential for fire-induced feeder root disease damage by *R. undulata* to conifer regeneration in the Northern Rocky Mountains is poorly defined. It is known, however, to be present in western Montana and northern Idaho (Weir 1915). The lack of recent reports on the fungus in this area may be due, at least in part, to effective fire exclusion and limitation. This parasite has demonstrated its potential to cause extensive damage to conifer seedlings and even mature trees in Great Britain and Europe (Gremmen 1971; Jalaluddin 1967; Murray and Young 1961). It has also been reported to be destructive to conifer seedlings in western Washington (Morgan and

[2]An inhibitory factor that limits germination of fungal spores in soils. Such a factor has been reported present in forest soils (Dobbs and Bywater 1959).

river 1973, 1972). One report associated this organism with a diseased condition in n 80-year-old spruce in Vermont (Thompson and Tattar 1973). Thus, although its otential in the Intermountain region is unknown, its presence here and its capability o infect conifer regeneration in recently burned areas are recognized.

After the initial soil microflora reductions following fire, microbial populations reater than the original can occur (Renbuss and others 1973; Ahlgren 1965). The presnce of potentially damaging feeder root diseases, including *Phytophthora*, *Pythium*, *usarium*, and *Rhizoctonia* in natural forest soils, and their survival after burns of arious intensities has been documented (Wright and Bollen 1961). Increases in damaging eeder root pathogens have been reported in postfire soils (Hartley and Pierce 1917); right and Bollen 1961; Tarrant 1956). Conversely, charcoal has been reported to educe damping-off of conifer seedlings (Beltram 1963; Radovanovic 1962; Commonwealth f Pennsylvania 1930; Boyce 1925). Very short exposures to increased soil temperatures esulting from prescribed fires or wildfires may cause shifts in species composition nd numbers of soil fungi (Peterson 1970; Seaver and Clark 1910). Increases in the ctivity of ascomycetes such as the root pathogen *Rhizina undulata* (Morgan and Driver 972; Ginns 1968; Jalaluddin 1968) after burning provide a specific example.

Alkaline shifts in soil pH have been well documented subsequent to site burning Neal and others 1965) and weakly acid, neutral, or alkaline soils are generally favorble to soil feeder-root pathogens. Seedling damping-off has been correlated directly o raising forest soil pH levels (Tarrant 1956). In addition, high moisture and lack f aeration may be caused by fire or harvesting practices (Ralston and Hatchell 1971; ethlahmy 1962) and are generally conducive to soil-inhabiting plant diseases (Raney 970). The effects of fire and nitrogen fertilization are similar (Sagara 1973) and igh nitrogen levels contribute to an increased susceptibility to feeder root diseases Rowan 1971; Foster 1968). This indicates a real possibility of feeder-root pathogen roblems, particularly on regeneration established during the early postburn period. he potential effects of these factors on the establishment of mycorrhizal associations Björkman 1970) and the apparent resistance to feeder-root pathogens provided by ycorrhizae (Marx 1973) provide an additional and potentially significant factor.

Clearcutting or burning may threaten the subsequent timber crop through excessive elease of nutrients. Changes in soil nutrients, particularly nitrogen, can influence isease (Hesterberg and Jurgensen 1972; Foster 1968; Sadasivan 1965). For instance, ecause the addition of nitrogen to forest nurseries increases incidence of damping-off iseases, applications are delayed until seedlings have grown beyond the susceptible tage (Rowan 1971; Foster 1968). Additions of nitrogen, phosphorus, and potassium to oung slash pine increased incidence of fusiform rust (Blair and Cowling 1974; Hollis nd others 1972; Gilmore and Livingston 1958; Bogess and Stahelin 1948). Conversely, egulation of soil nutrient balance can reduce incidence of this destructive pathogen Hollis, personal communication).

Root disease caused by *Fomes annosus* decreased when potassium and magnesium were dded to the soil, but increased with additions of manganese and increasing soil pH Yde-Anderson 1970). Froelich and Nicholson (1973) reported a reduction of *F. annosus* oot rot as large quantities of sulfur were added. This may have been more the result of lowering in soil pH than the increased levels of available sulfur in the soil. dditions of nitrogen alleviate little leaf disease (Roth and Copeland 1957; Roth and thers 1948), *Verticillium* wilt of maple (Caroselli 1956), and maple decline (Mader nd Thompson 1969).

Addition of soil nutrients probably influences disease through control of plant ealth and vigor. However, nutrients may also directly affect the survival and growth f the saprophytic stage of many root pathogens. Again, nitrogen or the form of itrogen can be significant (Huber and Watson 1974). Nitrogen level appears to egulate the formation and germination of *Fusarium* chlamydospores (Garrett 1970).

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SUMMARY

From the many potential effects on microbial ecology that could result from the practices of intensive fiber utilization or prescribed burning in forested ecosystems, four major functional areas directly influence subsequent site quality. These include: (1) decay with its effects on carbon transformations, carbon, and mineral cycling, and the associated soil development; (2) the formation and function of mycorrhizal roots; (3) fixation of N and its transformations; and (4) the development and damage caused by plant disease fungi. The existing literature on each of these subjects was intensively reviewed to provide the basis for the following tentative conclusions.

The processes and organisms involved in residues decomposition are essential to soil development through carbon and mineral cycling and conservation, and may contribute indirectly to nitrogen acquisition. Therefore, the rate of timber harvesting in conjunction with prescribed burning or intensive fiber utilization should be adjusted to provide an adequate organic matter base for these processes. Failure to do so in the past has resulted in decreased site productivity.

The obligate association between most conifers and their mycorrhizal partners emphasizes that management of forest ecosystems for optimal growth of selected species will require management of the fungal symbionts on which the trees depend. In several instances postharvest site treatments directly affected the ability of conifer seedlings to establish mycorrhizal associations.

Nitrogen is subject to various transformations by soil micro-organisms. Any changes in the physical and chemical properties of a forest soil will affect the activity of these organisms. The most important nitrogen-related microbial activities are the fixation of atmospheric N into a form usable by plants and the conversion of other forms of N into nitrate that is subject to leaching losses. These are directly responsible for the input and outflow of nitrogen in forest soils. Because of its importance to forest ecosystems, management activities should be directed toward providing maximum input and minimum outflow of nitrogen. Both burning and extensive fiber removal are known to influence nitrogen transformation.

Disease problems are not currently known to be greatly affected by residues management. Prescribed burning may increase the activities of the potentially damaging *Rhizina* root rot or other feeder root diseases on young conifer seedlings. Large buried residues, stumps, and roots infected by or subject to infection by several root pathogens are known to perpetuate such pathogens. In some circumstances proper management of such materials, or a lack thereof, could create significant impacts in post-treatment forests.

Harvey, A. E., M. F. Jurgensen, and M. J. Larsen
1976. Intensive fiber utilization and prescribed fire: effects on the microbial ecology of forests. USDA For. Serv. Gen. Tech. Rep. INT-28, 46 p. Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.

Reviews current knowledge of the effects of intensive wood utilization, prescribed burning, or a combination of both treatments, on the microbial ecology of forest soils. Identifies additional research that must be done to fill voids in knowledge.

OXFORD: 83/86; 436; 44.
KEYWORDS: utilization, residue management, prescribed fire, microbial ecology, decay, mineral cycling, mycorrhizae, nitrogen fixation, nitrification, mineralization, pathogen, disease, regeneration, forest ecology, site quality.

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U.S. GOVERNMENT PRINTING OFFICE: 1976

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FIRE IN MULTIPLE USE MANAGEMENT RD&A

PROGRAM

FOREST RESIDUES UTILIZATION

RESEARCH AND DEVELOPMENT PROGRAM

KEYS TO MMON PARASITES AND REDATORS OF THE UNTAIN PINE BEETLE

Lynn A. Rasmussen
Biological Technician

USDA Forest Service
General Technical Report INT-29, 1976
INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
Ogden, Utah 84401

Because they lack convenient reference material, investigators in the field often are handicapped in the identification of parasites and predators of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins).

The keys presented here were developed to aid identification in the field of the most common and perhaps the most important parasites and predators of the mountain pine beetle in the lodgepole pine (*Pinus contorta* Douglas) forests of the Intermountain area. These keys are intended to be used primarily with the unaided eye; however, a 10X hand lens may be needed in a few cases. The only stages included in the keys are those that are parasitic or predaceous--the larvae and adults of *Enoclerus sphegeus* Fabricius and *Thanasimus undatulus* Say (Coleoptera: Cleridae); and the larvae of *Xylophagus* sp., *Medetera aldrichii* Wheeler, and *Lonchaea* sp. (Diptera: Xylophagidae, Dolichopodidae, and Lonchaeidae, respectively); *Coeloides dendroctoni* Cushman, *Dinotiscus (=Cecidostiba) burkei* (Crawford), and *Roptrocerus eccoptogastri* (Ratzburg) (Hymenoptera: Braconidae, Pteromalidae, and Torymidae, respectively).

KEY TO LARVA

1. Larva with legs...
   Larva without legs..

2. Epicranium with dorsal tubercle on each side (fig. 1A,1B)....*Enoclerus sphe*
   Epicranium without dorsal tubercles (fig. 2A,2B)...........*Thanasimus undat*

3. Body slender and cylindrical with ventral pseudopodia...................
   Body spindle shaped or crescent shaped without ventral pseudopodia.........

4. Tentorial rods absent; first and second thoracic segments sclerotized dorsally; body and paired caudal protuberances with a number of long hairs (fig. 3)..*Xylophagus*

   Tentorial rods present; body hairless.....................................

5. Tentorial rods black; small, sclerotized plate on posterior region of head and anterior margin of prothorax (fig. 4)..................*Medetera aldri*

   Tentorial rods brown, fused at two points and branching caudally; sclerotized plates absent (fig. 5)................................*Lonchaea*

6. Body spindle shaped, tapering to a slightly rounded cephalic end and to a sharp caudal end; midlateral swellings present in the first eight abdominal segments (fig. 6)......................................*Coeloides dendroc*

   Body crescent shaped with a rounded cephalic end and a sharply tapering caudal end; midlateral swellings absent; head with several small spines (fig. 7)...*Dinotiscus bu*

   Body crescent shaped with a rounded cephalic end and a sharply tapering caudal end; midlateral swellings absent; head without spines (fig. 8)..*Roptrocerus eccoptoga*

KEY TO ADULTS

1. Clerid beetle with black legs..
   Clerid beetle with brown legs..

2. Both elytra marked at midlength with a wide transverse band of white, each elytron with short, narrow posterior white stripe, apices black (fig. 9)...*Enoclerus sph*

3. Both elytra marked at midlength with a narrow transverse band of white extending forward along the center, apices white or mostly so (fig. 10)..*Thanasimus unda*

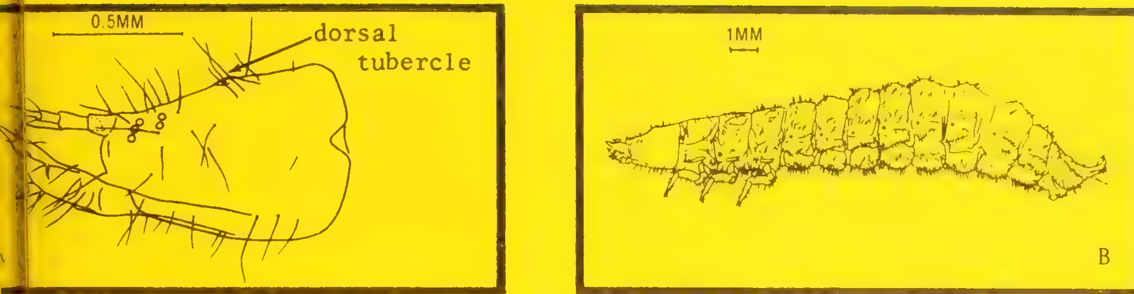


Figure 1.--*Enoclerus sphegeus;* lateral view of head (A) and larva (B).

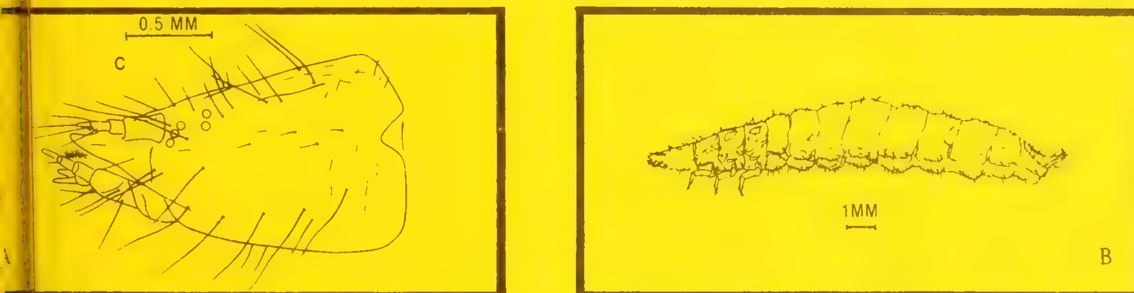


Figure 2.--*Thanasimus undatulus;* lateral view of head (A) and larva (B).

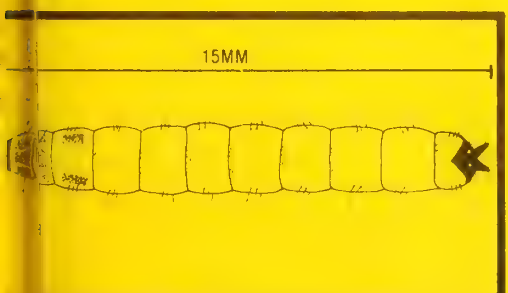


Figure 3.--*Xylophagus* sp.; dorsal view.

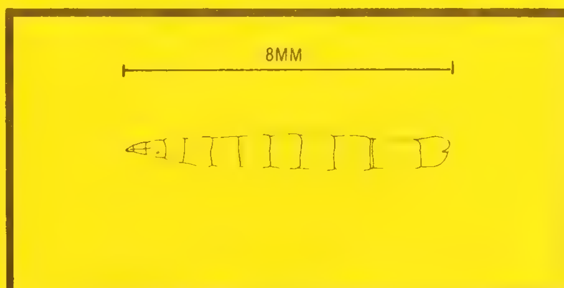


Figure 4.--*Medetera aldrichii;* lateral view.

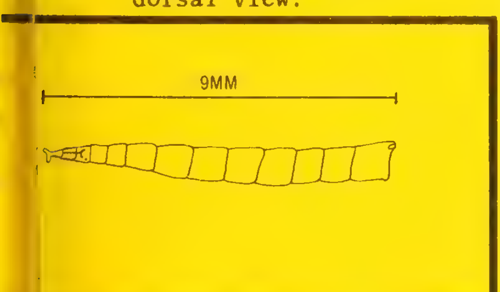


Figure 5.--*Lonchaea* sp.; lateral view.

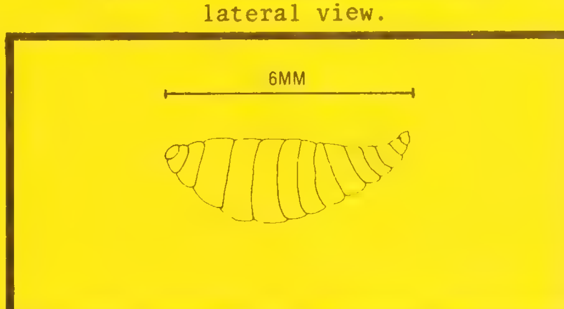


Figure 6.--*Coeloides dendroctoni;* lateral view.

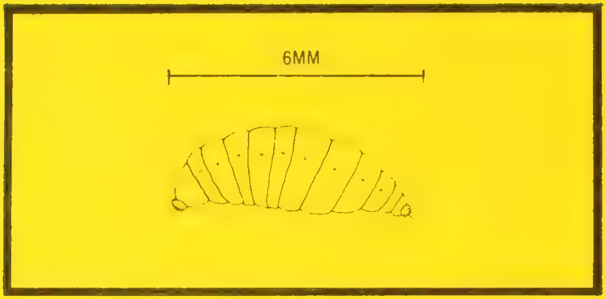


Figure 7.--*Dinotiscus burkei*; lateral view.

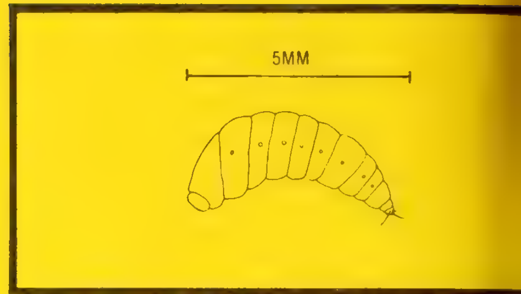


Figure 8.--*Roptrocerus eccoptogastr*
lateral view.

Figure 9.--*Enoclerus sphegeus*.

Figure 10.--*Thanasimus undatulus*

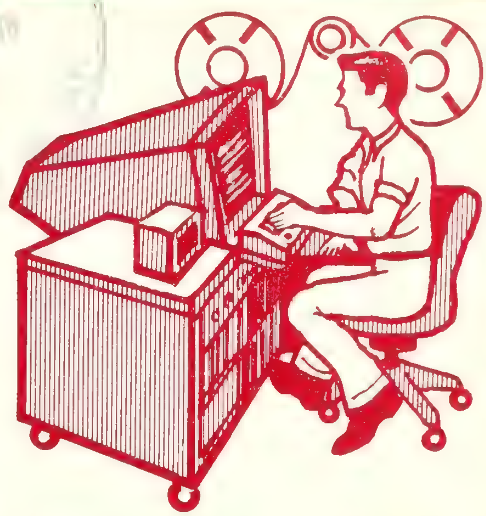
ACKNOWLEDGMENTS

I wish to thank Dr. J. A. Rudinsky, Oregon State University, for his permission to use figures 1A, 1B, 2A, and 2B; and Dr. W. P. Nagel, also of the Oregon State faculty, for his permission to use figures 9 and 10.--*Lynn Rasmussen*.

☆ GPO 1976

ESTIMATING WILDFIRE BEHAVIOR AND EFFECTS

Frank A. Albini



USDA Forest Service
General Technical Report INT-30

INTERMOUNTAIN FOREST AND RANGE
EXPERIMENT STATION

USDA Forest Service
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1976

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ACKNOWLEDGMENTS

The author gratefully acknowledges the most generous assistance and encouragement of many colleagues without whom this effort would have failed: James K. Brown, Hal E. Anderson, Richard C. Rothermel, and William C. Fischer, all of the Northern Forest Fire Laboratory. Special thanks are also due to some reviewers of the manuscript who made many specific and valuable technical suggestions: Craig C. Chandler, Director of Forest Fire and Atmospheric Sciences Research, Washington Office USDA Forest Service; George R. Fahnestock, Fire Research Coordinator with the Northern Forest Research Centre of the Canadian Forestry Service; Von J. Johnson, Project Leader at the North Central Forest Experiment Station, USDA Forest Service; Clive M. Countryman, Project Leader at the Pacific Southwest Forest and Range Experiment Station, USDA Forest Service; and Richard J. Barney, Research Scientist at the Northern Forest Fire Laboratory.

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ABSTRACT

This paper presents a brief survey of the research literature on wildfire behavior and effects and assembles formulae and graphical computation aids based on selected theoretical and empirical models. The uses of mathematical fire behavior models are discussed, and the general capabilities and limitations of currently available models are outlined.

Rothermel's fire spread model is used to develop nomographs for estimating rate of spread, reaction intensity, and flame length for a variety of "typical" fuel complexes, under widely variable conditions. Factors affecting spread rate and overall shape of a fire are quantified, as well as some fire effects such as crown scorching and duff removal.

Appendices give more details of the formulations presented graphically in the text, including the definitions of terms used to quantify fire behavior and effects and tables of numerical factors for converting values to different units of measurement.

INTRODUCTION

This document is an outgrowth of a short course in fire behavior estimation.[1] It is not intended to be an exhaustive survey or even a thorough introduction to the material, but a starting point from which the interested reader may venture into the literature of fire behavior modeling. Some theoretical and empirical relationships are presented, along with computation aids that may prove to be useful to those concerned with wildland fire behavior and effects.

Although fire behavior prediction is by no means a new field, the use of complex mathematical models for this purpose has only recently begun. The availability of computers has made the use of very complicated models a routine procedure in research, and allows complex calculations to be done by machines instead of people. The result is that more powerful models are now easy to use.

The purpose of this report is to introduce fire behavior specialists to some tools being developed in research which may be useful for predicting fire behavior. Through the process of constructive "feedback," research efforts can be tailored better to fit the needs of those who use research results. The continuation of such a dialogue about fire behavior modeling is actively being sought here.

USES OF FIRE BEHAVIOR MODELS

Potential uses of fire behavior models span the spectrum of fire-related decision-making. From land use planning to prescribed fire design, models are used to aid decisionmakers. The nature of the decisions being made, and the consequences of errors, determine the types of predictions and the degree of accuracy required of the model output. Here we review some model uses and indicate the type of output needed and the general level of accuracy each requires.

Fire-Danger Rating

Fire-danger rating is a management tool used to establish the degree of fire hazard and the risk of fire outbreak. On the basis of such assessments, decisions are made concerning land use and fire control readiness. The National Fire-Danger Rating System (NFDRS) (Deeming and others 1974) is a multiple-index scheme designed to provide fire control and land management personnel with a systematic means of assessing various aspects of fire danger on a day-to-day basis.

[1]Albini, Frank A. Advanced Fire Management Training Course, National Fire Training Center, Marana Air Park, Marana, Arizona, November 11-22, 1974.

Although easy to use because of its tables of indices, the system is based on complicated models of fire behavior. The multiple-index concept allows the assessme of different aspects of fire behavior (Deeming and others 1974; USDA Forest Service 1962). For example, in the National Fire-Danger Rating System, the spread component calculated from predicted forward rate of spread, the energy release component from rate of heat release per unit area, and the burning index from an estimate of flame length.

Model outputs need not be highly accurate for this use. It is important that t system of models (fire behavior models and fuel models) properly rank the fire behav variables estimated and that they respond to changes in weather consistently and wit sufficient sensitivity to permit decision boundaries to be established. For these purposes, stylized fuel models are entirely adequate, and indices of *relative* severi of fire behavior are sufficient.

Fire Control Planning

Fire control planning is a complex job of resource allocation. When, where, an to what level to man stations; the rules for initial attack dispatching; and the material to include in a fireline handbook may sound like unrelated questions, but t be answered they have a common need for data--estimation of fire behavior.

Although the estimation of wildfire behavior is a significant ingredient in the planning of fire control activities and the allocation of fire control resources, it by no means the only (and frequently not even the principal) ingredient. Considerat such as resource value threatened, relative risk of ignition, transportation, commun cations, equipment capabilities, etc., often dominate the problem of manning station and initial attack dispatching. The experienced fireman on the scene of a fire must be the source of predictions of potential fire behavior. The potential fire behavio entries in handbooks and training aids are only for purposes of quick, preliminary assessment.

Models that predict fire behavior can be useful in manning and dispatching plan if they are no more precise than the stylized models of the NFDRS; indeed, danger-ra indices themselves are used for these purposes. So the accuracy requirements for fi behavior estimation for these planning efforts are no more stringent than for fire-danger rating. This same general level of precision is probably adequate for firelin handbooks and similar training aids as well, but instead of indices, the models shou provide actual estimates of forward rate of spread, perimeter growth, intensity, fla length, etc.

These same kinds of estimates, except with slightly better accuracy (say, "fact of-two" accuracy?), might be useful to fire behavior officers. For quantitative est tion, if the models are easy enough to use under field conditions, and if they offer least enough resolution between fuel types to exhibit significant differences, model may be useful additions to the tools of the fire behavior officer's trade.

A set of working charts for estimating forward rate of spread, intensity, flame length, and crown scorch height are included in this document. This is done in hope that those concerned will try them and communicate to the author their assessments o the utility and accuracy of the charts. They are also intended for use as training aids and may be useful in some dispatching activities. Comments on these kinds of applications are also solicited.

Prescribed Fire Planning

Prescribed fires are used in many areas and for many purposes (Peet 1965; USDA Forest Service 1971; Fahnestock 1973; USDA Forest Service, n.d.). Hazard reduction (Pagni and others 1971; Green 1970; Schimke and Green 1970), species control (Pechanec and Blaisdell 1954), habitat improvement (Cushwa and others 1969; Leege 1968), silviculture (Roe and others 1971; Beaufait 1966), reduction of air pollution from wildfire smoke (Hall 1972; Mobley and others 1973; USDA Forest Service, n.d.), etc., are objectives of prescribed burning.

To plan prescribed fires to achieve stated objectives, to minimize cost of control and mopup, and to reduce the risk of escape or undesirable behavior, a firm basis of fire behavior estimation must be established. This basis should include not only the gross behavior of the fire but its effects on the surrounding environment. So, predictive models that allow the estimation of spread rate, intensity, flame length, etc., should be useful in prescription formulation but may not suffice to prejudge relevant fire effects such as fuel reduction, smoke generation, soil conditioning, and others.

Because specific effects are sought and specific sites are burned under preselected conditions to achieve them, in many cases prescribed burning poses the most stringent requirements for fire behavior prediction models. The use of preestablished fuel bed descriptions (such as the fuel models of the NFDRS) may be inappropriate for accurate prediction as the specific site being burned may differ substantially from the assumed fuel bed. But such "stylized" or "typical" models may be useful in establishing *roughly* what the fire behavior will be before the first burn, or for estimating what the sense and magnitude of *changes* in fire behavior will be as the burning conditions vary. The computation aids presented later in this document are offered with these intended applications in mind. There is no substitute for experience, but these tools may be useful aids in extrapolating from known to slightly different conditions when coupled with experience and careful observation.

CAPABILITIES AND LIMITATIONS OF SOME AVAILABLE MODELS

There are many mathematical models of varying scope and complexity that deal with many of the elements mentioned above. Most of these models reside in the literature, but some have been put into a form useful to nonresearch personnel. We will concentrate on a few models and mention others only in passing. The purpose of this cursory review is to introduce the reader not active in fire research to the literature of this field and to indicate roughly the present state-of-the-art of fire behavior modeling.

Scope of Predictions Possible

Mathematical models exist that relate physical and chemical properties of fuel arrays to specific fire behavior, such as forward rate of spread, fire intensity, flame length, burning time, and others. The environmental variables of windspeed and slope are also required to operate the models, as well as fuel moisture content.

Rates of fire spread and growth.--Using mathematical models published by the authors listed below, it is possible to calculate forward rates of spread for various fuel complexes.

Author(s)	*Publication date*	*Type of fuel array considered*
Fons	1946	Light forest fuels
Fons, Clements & George	1963	Laboratory wood cribs
Thomas & Simms	1963	Forest fuels (grass, brush)
Hottel, Williams & Steward	1965	Arrays of paper sheets
Albini	1967	Brush
Anderson	1969	Uniform porous bed
Fang & Steward	1969	Randomly packed fine particles
Thomas	1971	Cribs, gorse, and heather
Steward	1971	Mathematically describable bed
Frandsen	1971	Uniform porous bed
Rothermel	1972	General (uniform) wildland fuel
Pagni & Peterson	1973	Uniform porous bed

Of the models listed above, Rothermel's wildland fuel spread model (1972) is the most comprehensive and robust to date. It has been subjected to some direct verification tests in logging slash assembled fuel beds (Brown 1972) and both prescribed and wild grass fires (Sneeuwjagt 1974). Stevenson and others (1975) were also able to match observations and after-the-fact predictions of spread rate in mixed chaparral-li fuels using the Rothermel model in conjunction with an area-growth computer algorithm (Kourtz and O'Regan 1971). We will focus on this model at length in this paper.

The forward rate of spread of a wildland fire is only one descriptor of growth.[2] The growth rate of the perimeter of a large fire, as well as its area and the shape o the perimeter, are also useful quantities to predict.

A computer-based model of great mathematical elegance, but with a voracious appetite for data, has been developed by Kourtz and O'Regan (1971) and will be used in th FIRESCOPE computer-assisted Multi-Agency Coordination Center (Hanna and others 1974) to assess fire growth potential. The data that this model uses include the rate of spread from point-to-point; these quantities are generated by Rothermel's model in th application cited.

A much simpler model assembled by Anderson[3] from data taken by Fons[4] allows one estimate roughly the shape, size, rate of perimeter increase, and rate of area growth of a wind-driven wildland fire using only the forward rate of spread and windspeed as

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[2]Both George Fahnestock and Clive Countryman have pointed out to the author (private communications, 1975) that the term "rate of spread" has often been used to connote "rate of perimeter growth." The term "forward rate of spread" should be use to indicate head fire linear rate of advance. Current usage seems to favor the short phrase "rate of spread" for head fire rate of advance, but this unfortunate confusio of terms will no doubt persist for some time. Here we shall be explicit when referr to perimeter (or area) growth and use the phrase "rate of spread" for head fire rate advance.

[3]Anderson, Hal E. Memorandum to R. C. Rothermel and W. C. Fischer on file at t Northern Forest Fire Laboratory, Missoula, Montana, August 10, 1973.

[4]Fons, Wallace L. Unpublished data on rate of growth and fire shape. On file Pacific Southwest For. and Range Exp. Stn., For. Fire Lab., Riverside, Calif. [n.d.]

inputs. Van Wagner (1969) proposed a very similar method that predicts the same quantities; this method uses three rates of advance of the fire front--heading, flanking, and backing.

Fire intensity and related effects.--Byram (1959) defined a rather basic measure of fire intensity which has been proven very useful. Byram's fireline intensity has been used in describing the difficulty of controlling a fire because of the heat it produces (Hodgson 1968) and to predict or correlate flame length (Byram 1959), the height of scorching of conifer crowns (Van Wagner 1973), and the occurrence of spotting (Hodgson 1968). These relationships make this measure of intensity very valuable in fire behavior prediction. This intensity is defined as the rate of heat release per unit length of fire edge, and so is proportional to the rate of advance perpendicular to the edge.

Using a simple relationship between fuel particle size and burning time (Anderson 1969), or flame residence time, Rothermel's model can be used to predict Byram's intensity and the related aspects of fire intensity correlated to it.

Rothermel (1972) and Anderson (1969) make use of a different measure of intensity--the rate of heat release per unit area burning. This quantity appears directly in Rothermel's spread model and can be used in Thomas' (1963) equations correlating flame length and height with fire mass release rate. Thomas' equations are somewhat difficult to use in describing wildland fire flame behavior but usually predict a flame length approximately equal to that given by the equation given by Byram if one uses the flame width predicted by Anderson's relation as the characteristic dimension D in Thomas' equations.

Limitations on Accuracy of Predictions

The mathematical models cited above permit one to calculate various features of fire behavior. Some are easy to use, some very complicated, but all will be found to produce results which do not always agree with observed fire behavior. In some instances, the disagreement can be quite significant (Brown 1972; Lawson 1972).

There are three principal reasons for such disagreement, no matter which models are used:

1. The model may not be applicable to the situation.

2. The model's inherent accuracy may be at fault.

3. The data used in the model may be inaccurate.

Model applicability.--If one applies a model in a situation for which the model was not intended to be used, the "error" in the model's prediction can be very large. All the models discussed and cited above have the following limitations and should not be expected to predict what they do not pretend to represent:

1. The fuel bed modeled is continuous, uniform, and homogeneous. The more the real fuel situation departs from this ideal, the more erratic the predictions will be when compared to real fire behavior.

2. The fuel bed is a single layer and is contiguous to the ground, not an aerial layer, such as the crowns of coniferous trees. Although brush fires may technically be considered "crown fires" and have been treated by some of the above-mentioned models, a large-scale conifer crown fire is *not* specifically modeled and would probably be poorly predicted.

3. Fire spread by spotting (flying embers or firebrands) is not modeled by any of the models mentioned above, so fire spread rate in those situations where spotting is important will likely be poorly estimated.

4. Fire whirlwinds and similar extreme, fire-induced atmospheric disturbances are not modeled. Countryman (1971) provides guidance as to when such phenomena are to be expected, but actual predictions are not yet within the state-of-the-modelers'-art.

Accuracy of model relationships.--Wildland fires, being infrequent, unpredicted, and often occurring in inconvenient locations, are not ideal candidates for instrumentation and measurement. As a consequence, data to test theoretical or empirical formulae for wildfire behavior accumulate slowly. Model testing probably will continue to rely mostly on laboratory experiments and prescribed fire data, with occasional "windfall" wildfire observations.

The relationships between variables in all of the models must be viewed as weakly tested, semiempirical, and subject to exception. Where tests have been possible with sufficient rigor to test model relationship accuracy, they have usually shown the prediction errors to be within a few tens of percent on the average. Fire behavior varies over many orders of magnitude, and model builders consider models successful if the relationships predict fire behavior within a factor of two or three over a range of two or three decades. This can be taken as roughly representative of the current state-of-the-art in fire behavior model accuracy, including both the effects of applicability and internal accuracy. So until the limitations of model applicability outlined above are relaxed by further research, improvements in model relationship accuracy beyond the current level are unlikely to increase the overall accuracy of predictions.

The most important source of error in any particular prediction may be difficult to pin down to model applicability, model accuracy, or data accuracy. But the *internal consistency* of a well-disciplined mathematical model allows one to use it to assess the impact of changes in important variables for specific situations, even if the model overpredicts or underpredicts systematically, whether due to model inapplicability, model inaccuracy, or data errors.

For example, the effect of a 5 mi/h windspeed *increase* on the rate of spread in a grass-type fuel can be predicted to within a few tens of percent using Rothermel's (1972) model, but a specific prediction of spread rate at one windspeed in the same fuel type may be a factor of two high or low (Sneeuwjagt 1974).

Accuracy of data.--Fire behavior models should be sensitive to those parameters known to affect fire behavior, such as variations in fuel moisture, windspeed, slope, fuel bed depth, and others. If these data are not known accurately enough, model output may be significantly in error. It is easy to recognize the nature of and the effects of errors in data such as the windspeed, the slope, or the fuel moisture content. More subtle, yet equally important descriptors, such as fuel particle surface/volume ratios, the loading of fuel components in each size class, and the proportions of live and dead components, must also be specified accurately in order to predict fire behavior realistically. Rothermel's (1972) figures 24 and 25 illustrate dramatically the importance of these fuel bed descriptors in determining predicted fire intensity and forward rate of spread.

Because models of phenomena as complex as wildfire are, generally, quite nonlinear, the output may be highly sensitive to a particular parameter over one range of values and nearly insensitive to the same parameter in a different value range. For this reason, it is difficult to make a valid quantitative statement about the relationship between input data accuracy and output accuracy. The model in question must be used to establish its requirements for data accuracy, considering the range of values of the variables used for input.

If any general rule is valid, however, it is that most likely data accuracy will iot be the factor which limits the validity of behavior model predictions. The usually lominating error source is that the fuel complex is not uniform, continuous, homogen-ous, and consolidated into a single layer. Nor is the windspeed constant, the slope verywhere the same, nor the fuel moisture content the same from place to place. After iodel applicability, probably the next most important error source is inherent model ccuracy. If standard fuel inventory techniques are followed (Brown 1971, 1974; Van agner 1968b; USDA Forest Service 1959), it is unlikely that data accuracy would be he dominant error source. If no measurements are made, however, but estimates from bservations are used, the accuracy of the estimates may cause errors as large as the irst two sources, or even larger.

SOME FIRE BEHAVIOR COMPUTATION AIDS

In this section, some graphical results from the physical and mathematical rela-ionships that make up some specific fire behavior prediction models are presented, and he reader is referred to some others. The presentation here will be brief by neces-ity. The interested reader is urged to consult the original documentation for a better nderstanding of the various models.

To apply models predicting fire behavior, it is necessary to have in hand specific efinitions of the terms used to describe the phenomena. Appendix I discusses phenomena nd defines their descriptive terms, and gives some tables showing conversion factors etween various common units of measurement.

Appendix II presents and discusses the various models used in calculating the esults given here. The discussions are brief, but the equations are given for the nterested reader.

Rothermel's Spread Rate Model

Frandsen (1973a) programed a Hewlett-Packard Model 9820 minicomputer to cal-ulate intensity and rate of spread from Rothermel's model. Recently, this program has een revised and extended by Ms. Patricia Andrews of the Northern Forest Fire Laboratory. its current version, the program will not only solve a single problem, but will roduce graphs of spread rate versus windspeed and/or reaction intensity versus fuel oisture. Written instructions on the operation of the new program can be obtained by riting to Ms. Andrews.

The Northern Forest Fire Laboratory maintains a computer-based library of fire ehavior models at the Lawrence Berkeley Laboratories computer facility on the campus f the University of California at Berkeley. A Users' Manual (Albini 1976) is in reparation; draft copies are available from the author. Listing and card images of e FORTRAN IV source code are also available.

Nomographs for Stylized Fuel Models

By using Rothermel's equations (appendix II) and some stylized fuel models simila to those employed in the NFDRS (Deeming and others 1974), a set of graphs has been drawn that together can be used to estimate fire behavior in a wide variety of situations. A set of graphs has been constructed and organized for easy use. The fuel models used are described in detail in table 7, appendix III.

These sets of graphs, or working charts, are technically called nomographs, meaning graphical aids for the computation of numbers. The nomographs are collected at the end of this section.

The mathematical basis for the nomographs is the rate of spread model (Rothermel 1972) with minor modifications, as discussed in appendix III. Thus, the fire behavio described by the nomographs pertain to the leading edge of a spreading surface fire. *It does not include* spread by spotting (firebrands or embers), crown fire (spread through coniferous tree crowns), or the long-term residual fire intensity.

How to Use the Nomographs

1. Determine the best fuel model to use. The 13 fuel models contained in the se of nomographs are grouped into four general fuel community groups:

Grass and Grass-Dominated Fuel Complexes
Chaparral and Shrubfields
Timber Litter
Logging Slash

Although identified by an explicit, short name, the model usually will apply to more than one fuel situation. For example, fuel model 2, labeled "Timber (Grass and Understory)," also can be used for fire behavior assessment of southern pine clearcut slash. And fuel model 4, labeled "Chaparral (6 ft)," can also be used for heavy fres "red" conifer logging slash.

Each of the fuel models in each general group has a set of brief descriptions of applicable "best-fits" fuel types and "can-also-be-used-for" fuel types. The reader is urged to skim over the four pages separating the groups of fuel models to become far with the variety of models available and fuel communities to which they are intende to apply.

2. Determine the "variable" factors: windspeed, terrain slope, and fuel mois A working chart in the lower left-hand quadrant of each fuel model allows one to co the measured 20-ft windspeed and the slope tangent to obtain an "effective windspee The procedure is explained in the text accompanying the chart on each figure.

For fires not driven by the prevailing wind (e.g., backing or flanking fire), zero windspeed.

Fuel moisture for the dead fuel components can be taken from fire-danger ratin assessments, fuel stick measurements on site, or from any other appropriate source. For models 1-5 and 8-10, use the 1-hour timelag fuel moisture. For models 6 and 7, if the data are available, combine the three moisture contents as follows:

$$\text{"Dead Fuel Moisture"} = 0.89 \times (\text{1-hour timelag moisture}) + 0.09 \times (\text{10-hour timelag moisture}) + 0.02 \times (\text{100-hour timelag moisture}).$$

or the logging slash models, 11-13, combine the three moisture contents as follows:

"Dead Fuel Moisture" = 0.76 × (1-hour timelag moisture)

+ 0.18 × (10-hour timelag moisture)

+ 0.06 × (100-hour timelag moisture).

Live fuel moisture (foliage moisture) is required for models 2, 4, 5, 7, and 10. f data are unavailable for estimating such moisture, the following rough estimates ased on the stage of the dominant cover species in its annual cycle can be used:

300 percent--Fresh foliage, annuals developing, early in growth cycle.

200 percent--Maturing foliage, still developing, with full turgor.

100 percent--Mature foliage, new growth complete and comparable to older perennial foliage.

50 percent--Entering dormancy, coloration starting, some may have dropped from stems.

3. Proceed to calculate fire behavior using the nomograph with the appropriate ffective windspeed range. For each fuel model, there are two nomographs--one for low nd one for high windspeeds.

A. Enter the nomograph, via the upper right-hand scale, at the appropriate Dead Fuel Moisture." Draw a horizontal line across the page at that point.

If only dead fuel is present in the fuel model, determine the point of ntersection of this horizontal line with the S-shaped curve in the upper right-hand uadrant. From this point of intersection, draw a vertical line down through the lower ight-hand quadrant. Call this "line A." Go on to step B, skipping the following steps.

If both live and dead fuels are present in the fuel model, determine the oint of intersection of the horizontal line with the curve in the upper right-hand uadrant, which corresponds to the live fuel (foliage) moisture. Interpolate if ecessary. These curves are labeled and also distinguished by different dot-and-dash atterns. From this point of intersection, draw a vertical line down through the ower right-hand quadrant. Call this "line A." *Continue the horizontal line* through he upper left-hand quadrant, connecting it to the "Dead Fuel Moisture" scale on the pper left-hand scale at the same value used to enter the nomograph on the upper ight-hand scale.

The curves in the upper left-hand quadrant are labeled with the various ive fuel moistures and are drawn with the same dot-and-dash patterns as their orresponding curves in the upper right-hand quadrant. *If the horizontal line intersects* the curve in the upper left-hand quadrant for the live fuel moisture being sed, *then draw a straight line* through this point of intersection to the lower right-and corner of this quadrant. Call this "line K." You will use this constructed line ater, in step D. *If the horizontal line does not intersect* the curve of live fuel oisture being used, *you will not need to use a constructed line* in step D.

B. Line A, constructed in step A, extends vertically into the lower right-and quadrant, crossing the lines labeled "Effective Windspeed" in that quadrant. You hould already have determined the value of the effective windspeed using the small raph inset in the lower left-hand quadrant. If not, do so before proceeding; the

instructions are printed below the graph on each page. Determine the point of intersection of the vertical line with the line labeled with the value of the effective windspeed, interpolating if necessary. From this point of intersection, draw a horizontal line across the bottom of the nomograph, extending through the lower left-hand quadrant.

C. Determine the point of intersection of the horizontal line constructed in step B with the diagonal line in the lower left-hand quadrant. From this point of intersection, draw a vertical line into the upper left-hand quadrant, passing through the lines drawn in that quadrant.

D. *If only dead fuel is present in the fuel model*, then determine the point of intersection of the vertical line constructed in step C with the line labeled with the appropriate 1-hour timelag fuel moisture, interpolating if necessary. From this point of intersection, draw a horizontal line back through the upper right-hand quadrant. Call this "line D." Go on to step E and read results.

If both live and dead fuels are present in the fuel model, then the next step depends upon whether or not you constructed line K in step A. *If line K was constructed*, determine its intersection with the vertical line constructed in step C. From this point of intersection, draw a horizontal line back through the upper right-hand quadrant. Call this "line D." Go on to step E and read results. *If you did not have to construct line K* in step A, then locate the curve labeled with the value of live fuel moisture used in step A, interpolating if necessary. From where this curve intersects the vertical line constructed in step C, draw a horizontal line to the right, through the upper right-hand quadrant. Call this "line D."

E. Read results at three places:

(1) Line A crosses the horizontal axis separating the two right-hand quadrants. Read the scale at that point to determine the reaction intensity (see appendixes I and II) of the fire.

(2) Line D crosses the vertical axis separating the two upper quadrants. Read the scale at that point to determine the forward rate of spread of the fire.

(3) Line A (extended upward if necessary) and line D intersect in the upper right-hand quadrant. The flame length at the front of the fire can be determined from this intersection point. Interpolate between the hyperbolic curves (those that run from upper left to lower right in a rounded L shape), which are labeled with the values of flame length.

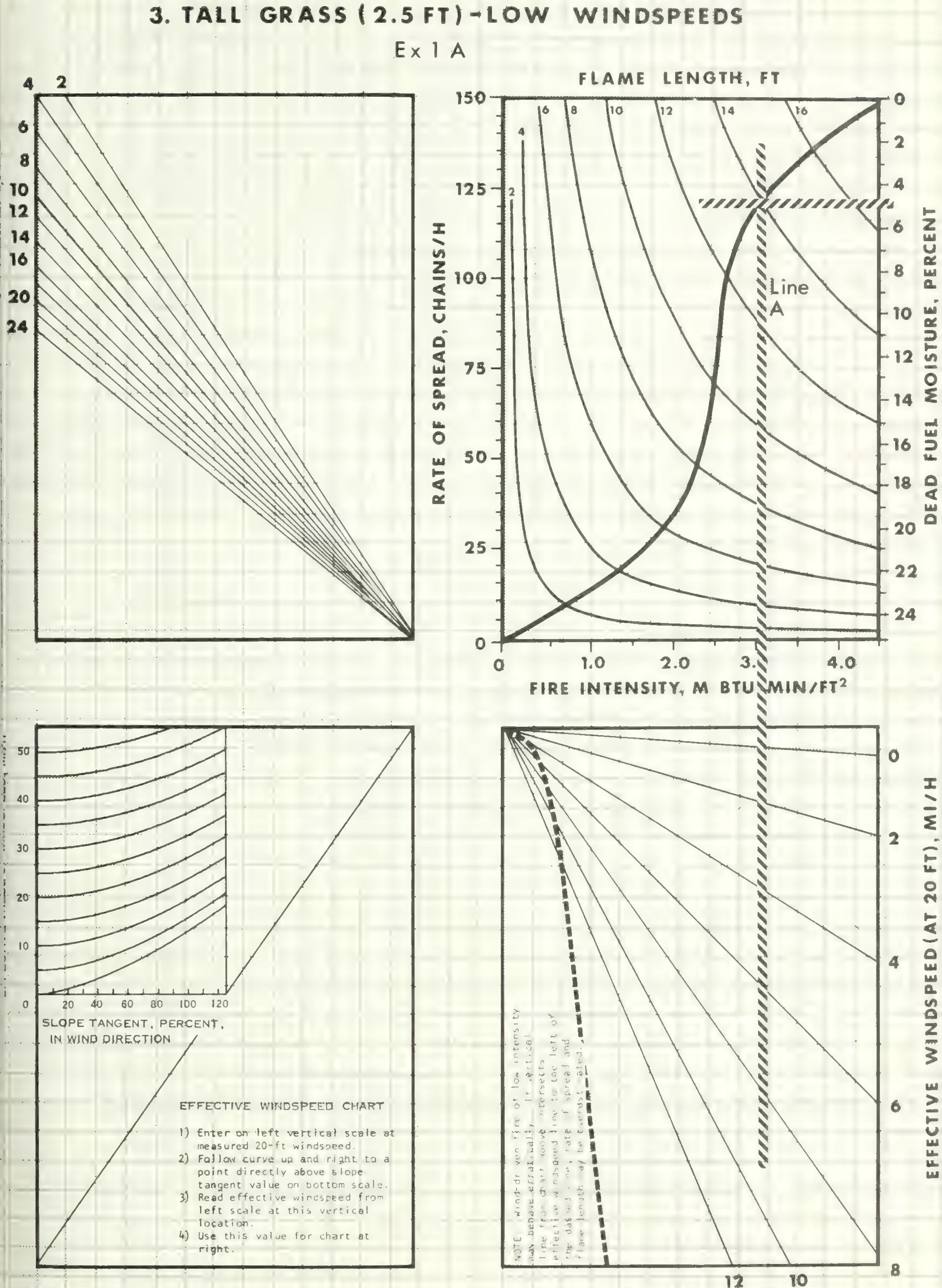
Examples

Two examples are worked out step-by-step on the following pages, one step per page. Each page is marked with the letter of the step in the instruction sequence just above. To follow the steps in the construction of the solution to each example, match the letter of the instruction steps (A-E) with the page. On each page, the lines constructed in that step are shown dashed, previously completed lines solid. The data for the two examples are given below:

Example 1 (fig. 1).--Estimate the fire intensity, forward rate of spread, and the flame length of a fire in cured broomsedge, given a fuel moisture content of 5 percent and a windspeed (at 20-ft height) of 8 mi/h, on level ground.

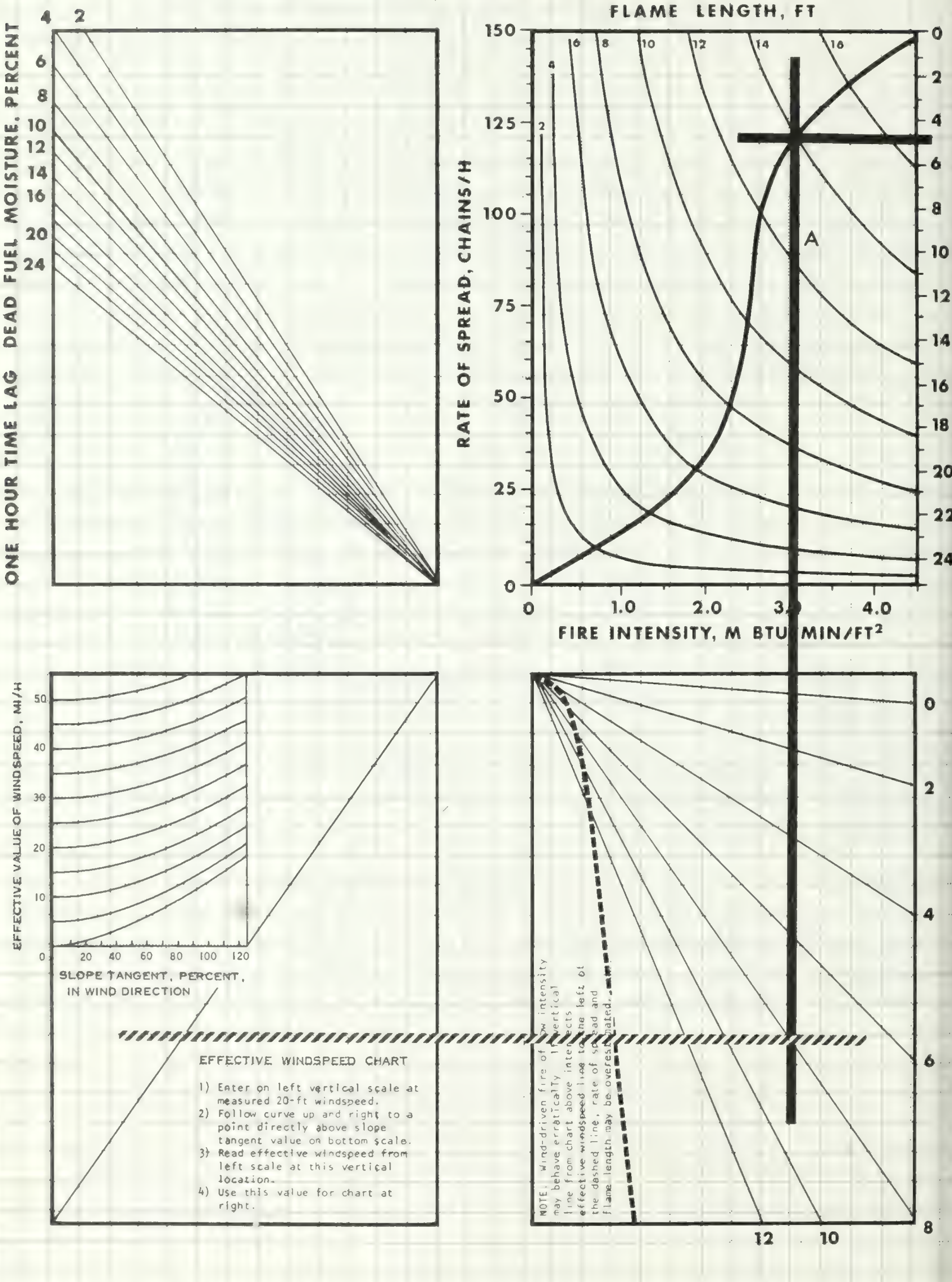
Solution 1.--Verify that the appropriate fuel model is number 3--Tall Grass (2.5 ft). The chart to use is the "low windspeed" member of the pair. The results of the construction illustrated on the following pages are: fire intensity, 3,000 Btu/min/ft^2; rate of spread, 97 chains per hour; flame length, 12.5 ft.

Figure 1.--Example 1, parts A through E.



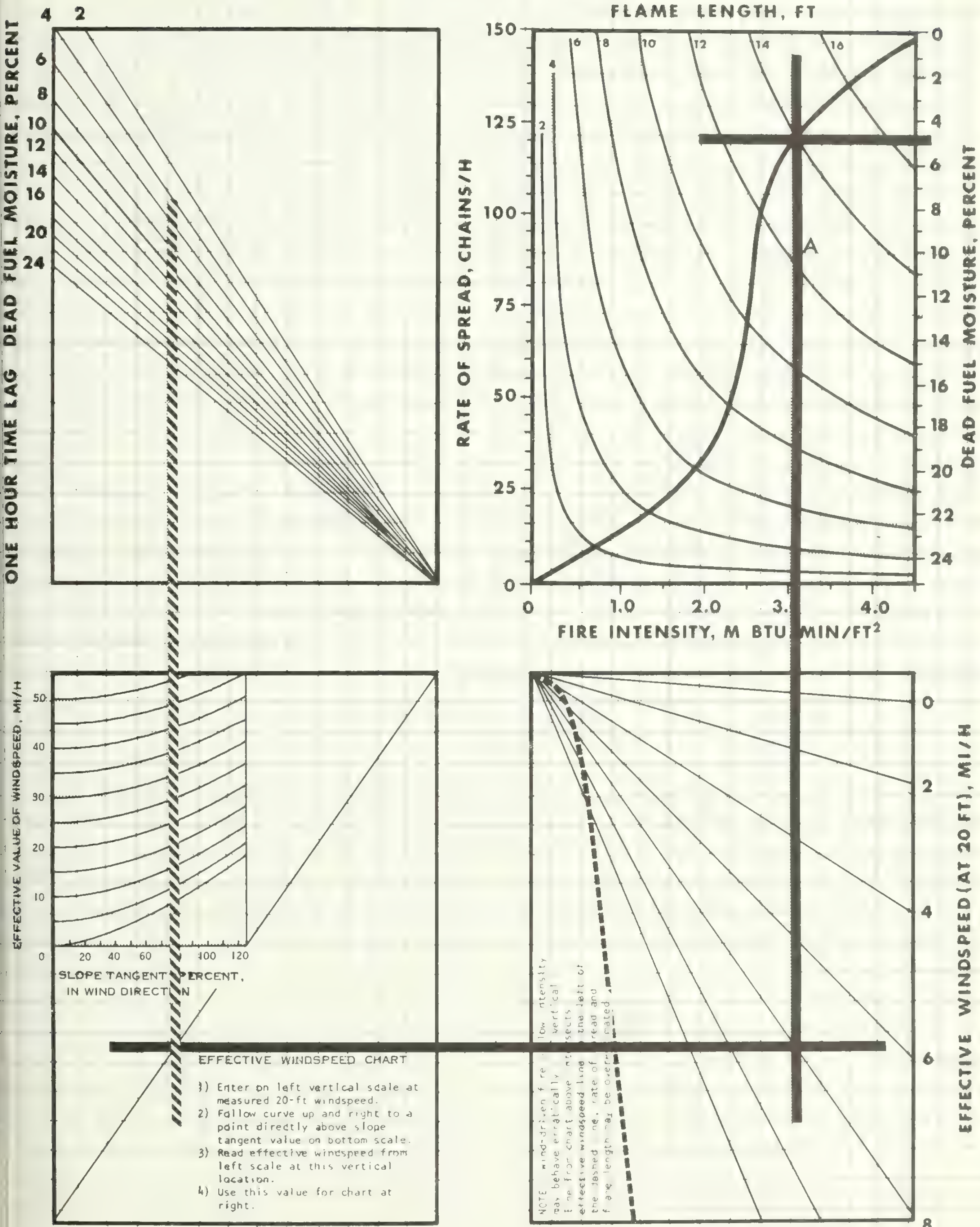
3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS

Ex 1B



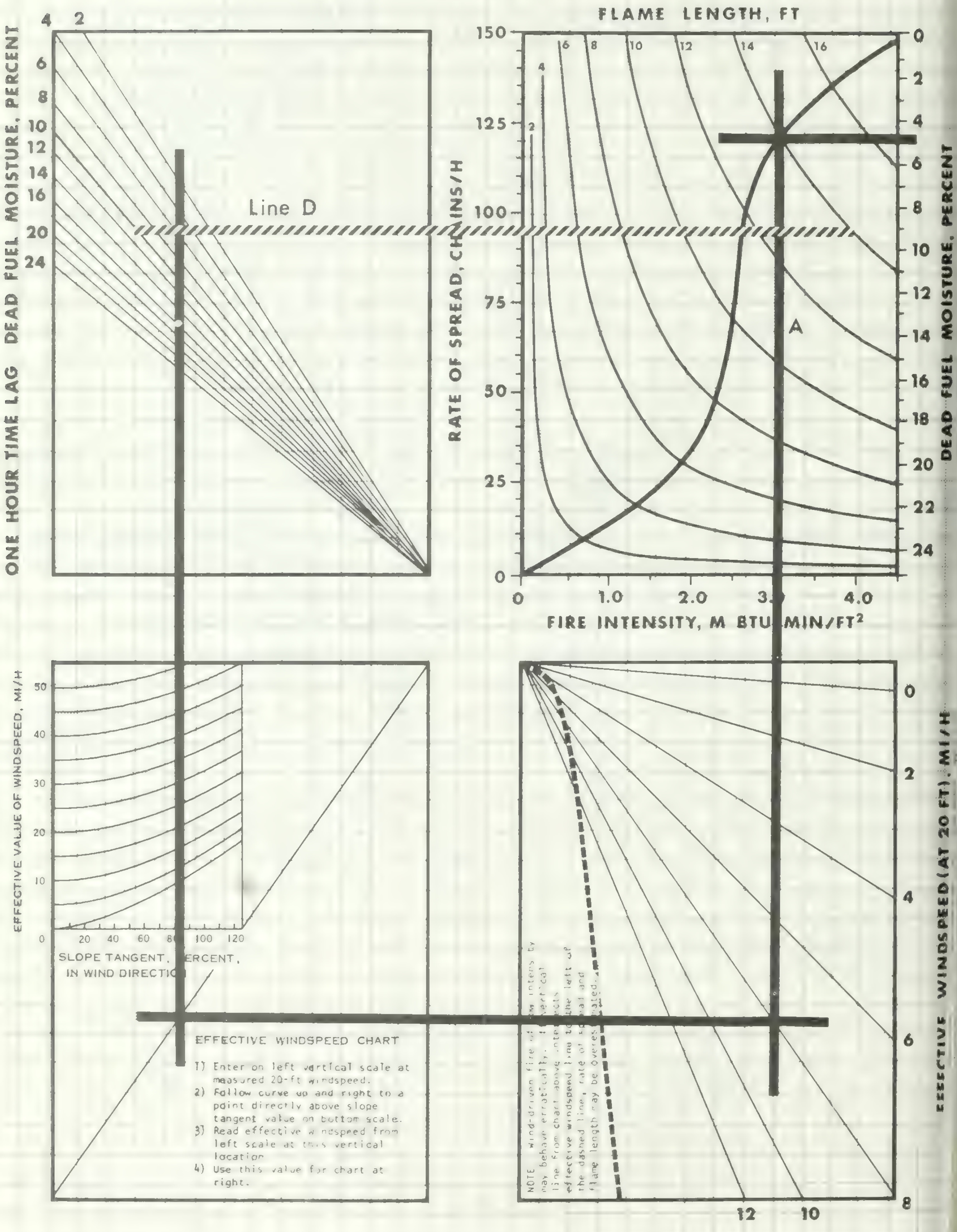
3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS

Ex 1C



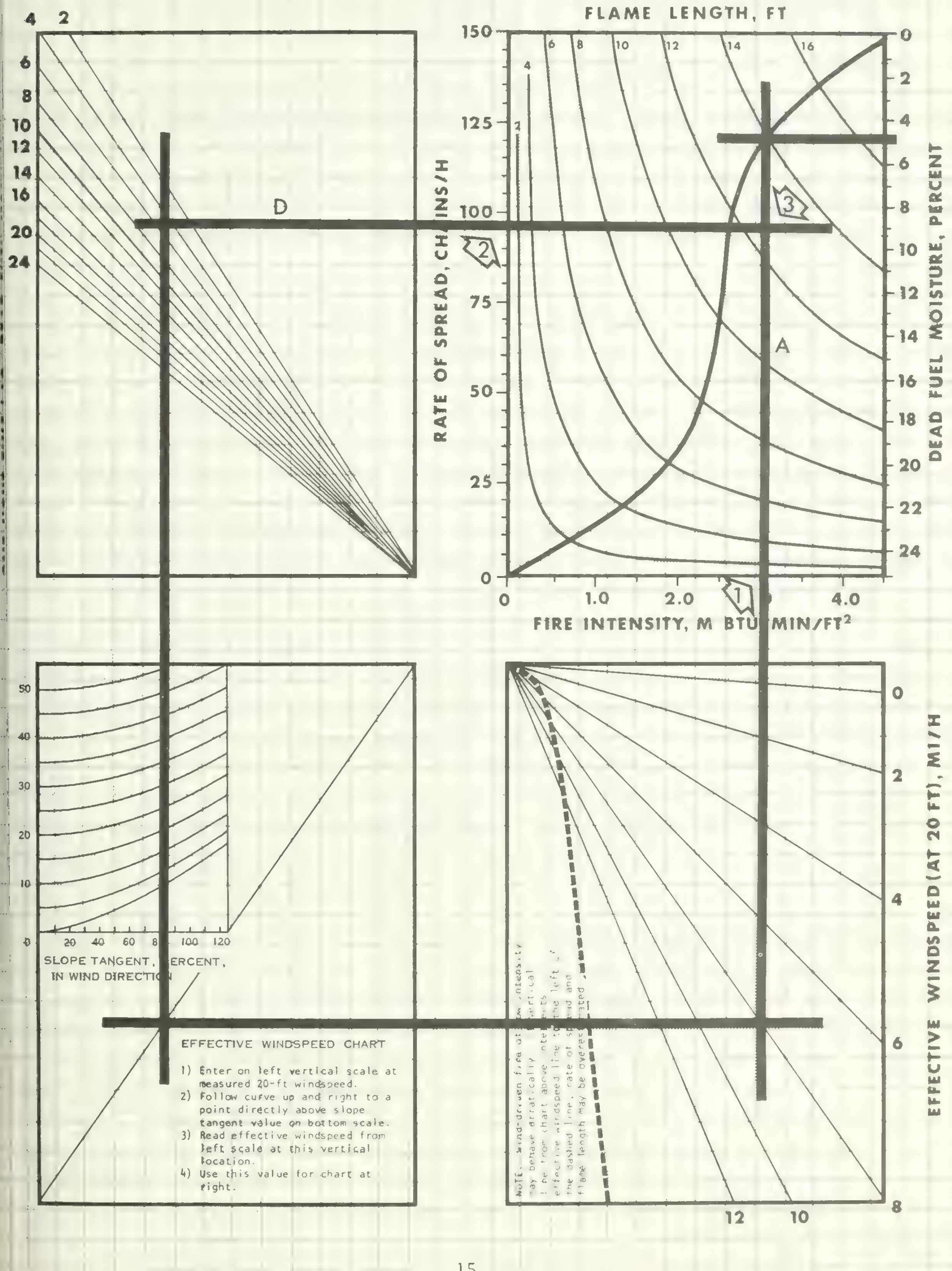
3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS

Ex 1D



3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS

Ex 1E

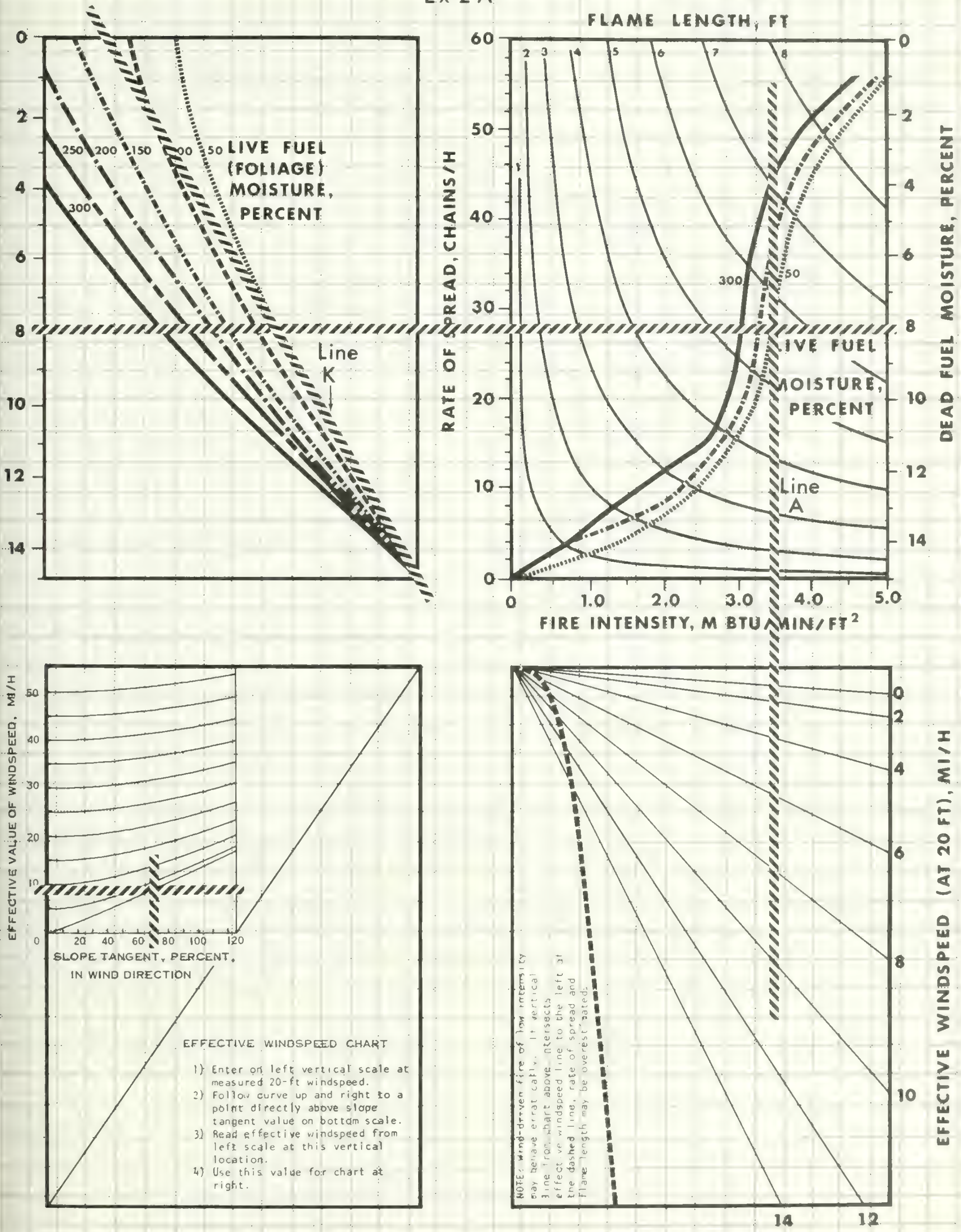


Example 2 (fig. 2).--Estimate the fire intensity, forward rate of spread, and the flame length of a fire in a wiregrass/scrub oak association, when the fine dead fuel moisture is 8 percent, the live foliage moisture about 50 percent, the wind is calm, and the slope is 70 percent.

Solution 2.--Verify that the proper fuel model to use is number 2, Timber (Grass and Understory). The chart to use is once again the "low windspeed" version. Using the small chart inset in the lower left-hand quadrant of this nomograph, verify that the effective windspeed is 9 mi/h. The results of the construction illustrated on the following pages are: fire intensity, 3,500 Btu/min/ft^2; rate of spread, 34 chains per hour; flame length, 6.2 ft.

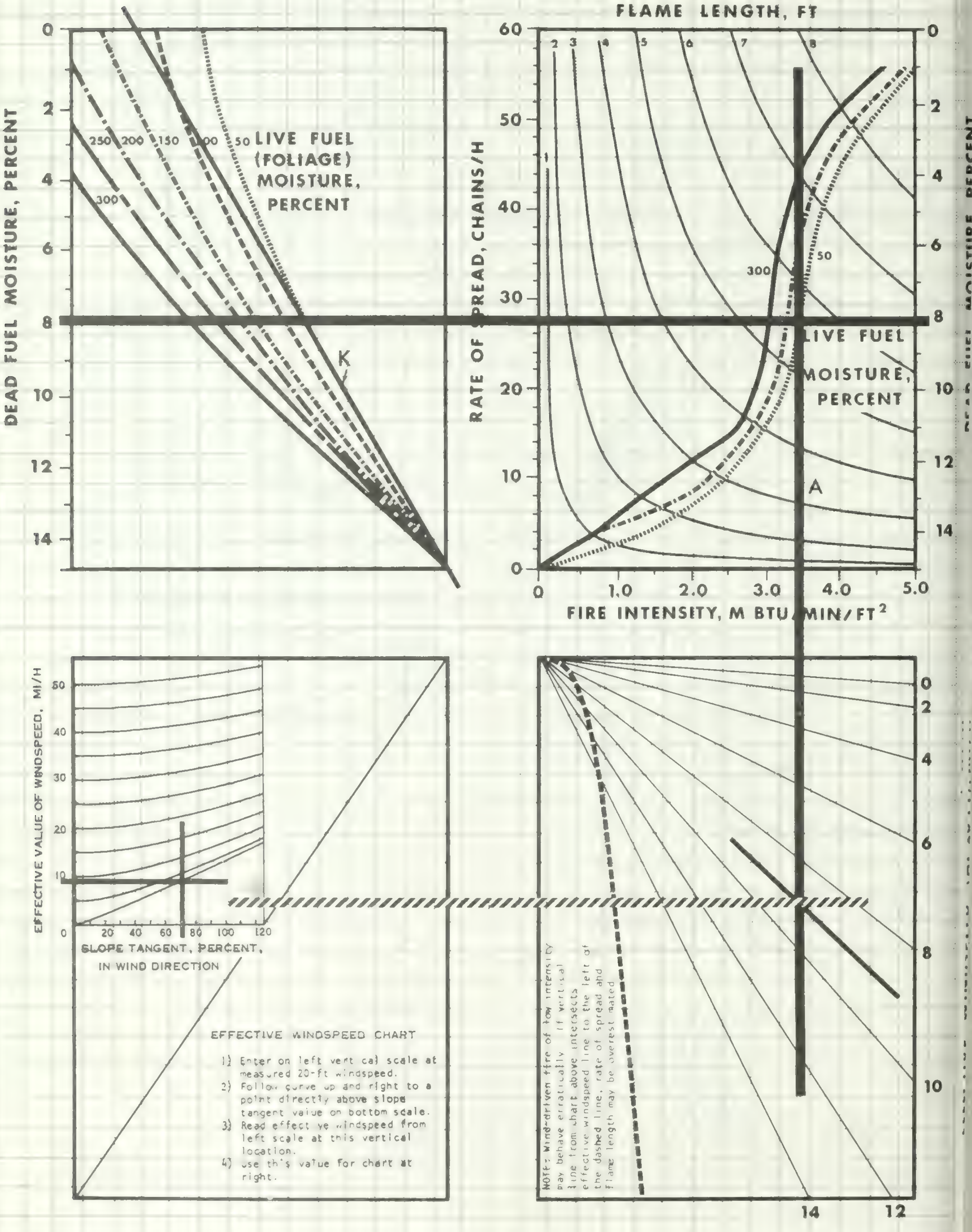
2. TIMBER (GRASS & UNDERSTORY) - LOW WINDSPEEDS

Ex 2A



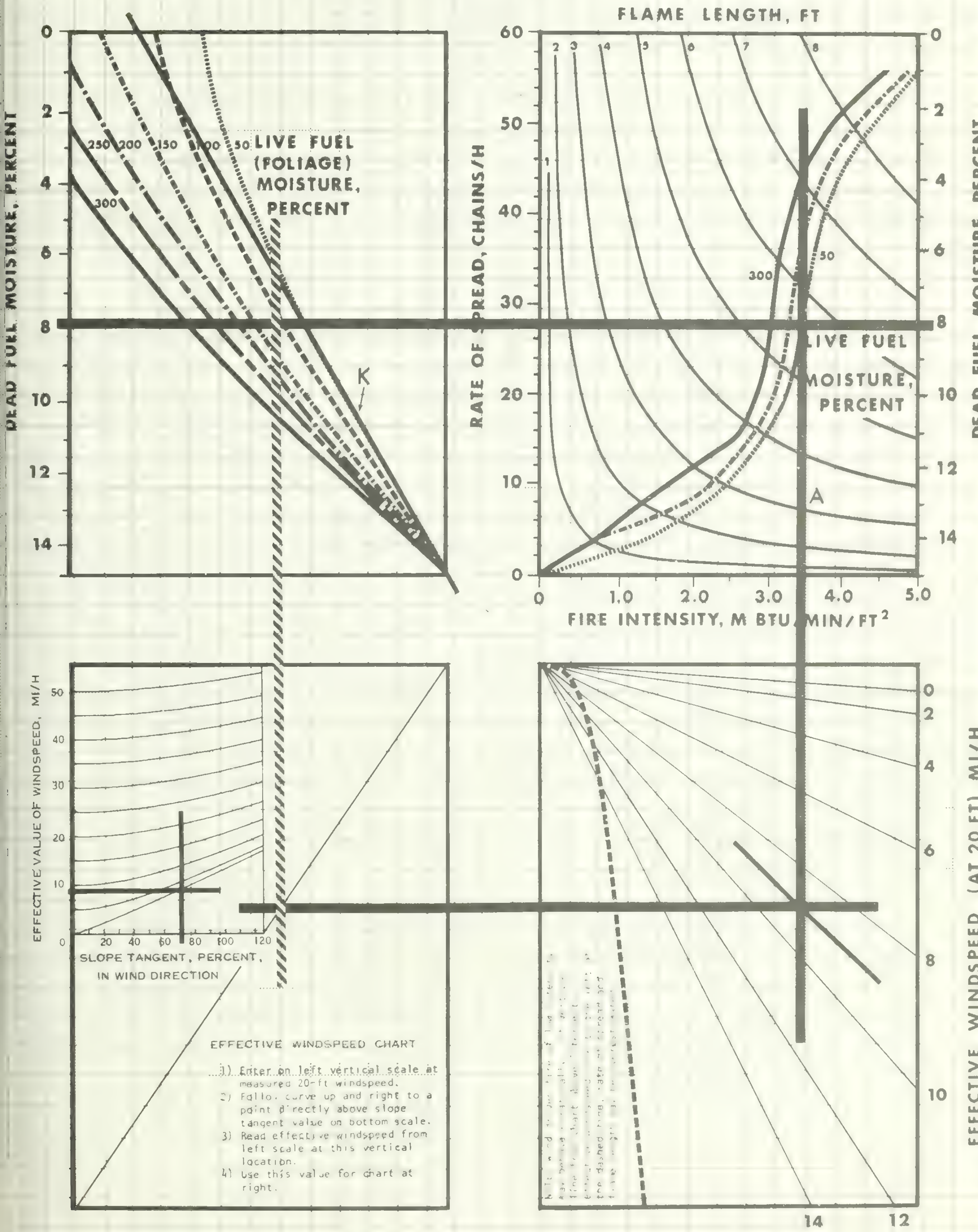
2. TIMBER(GRASS & UNDERSTORY)-LOW WINDSPEEDS

Ex 2B



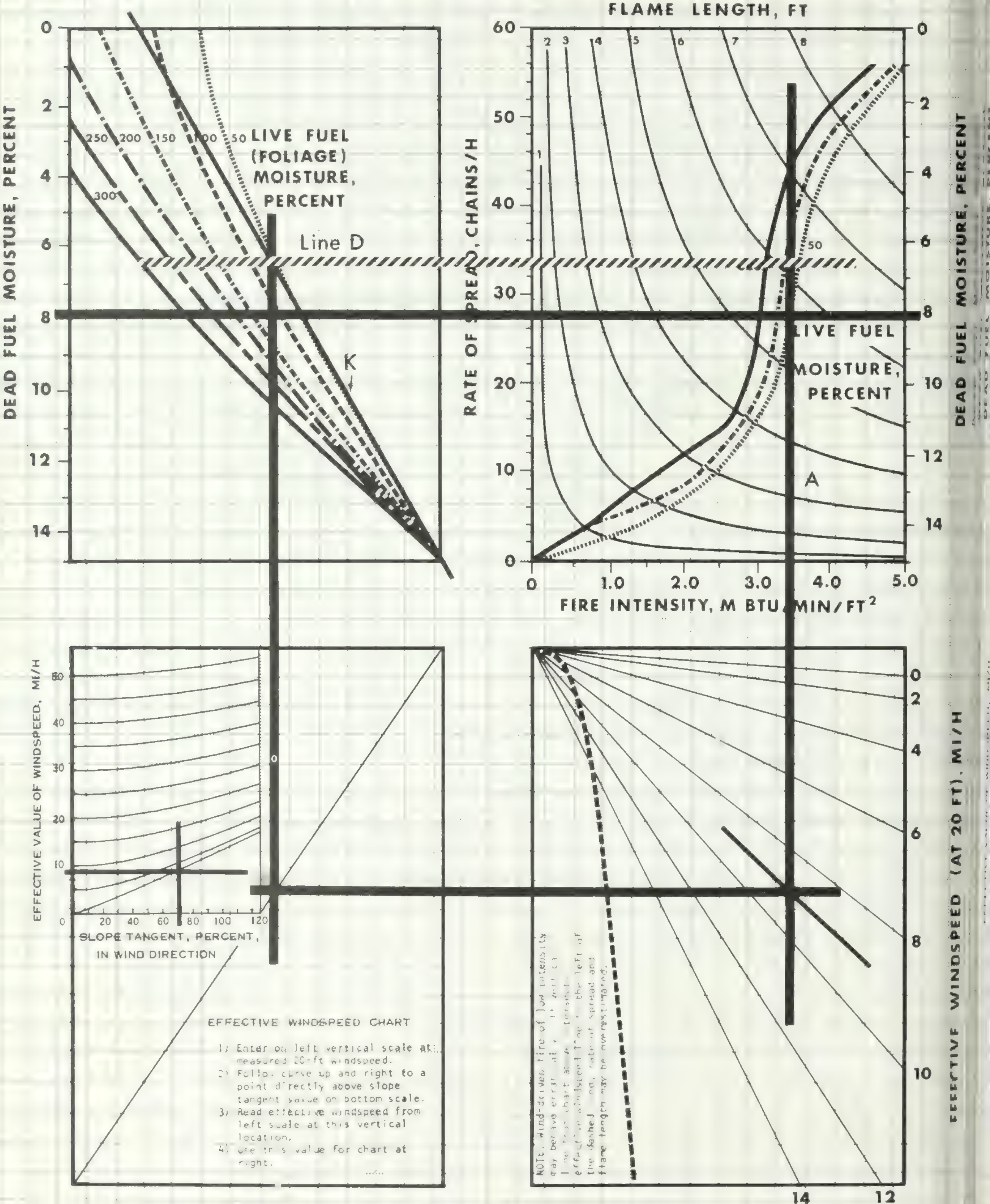
2. TIMBER (GRASS & UNDERSTORY) - LOW WINDSPEEDS

Ex 2C



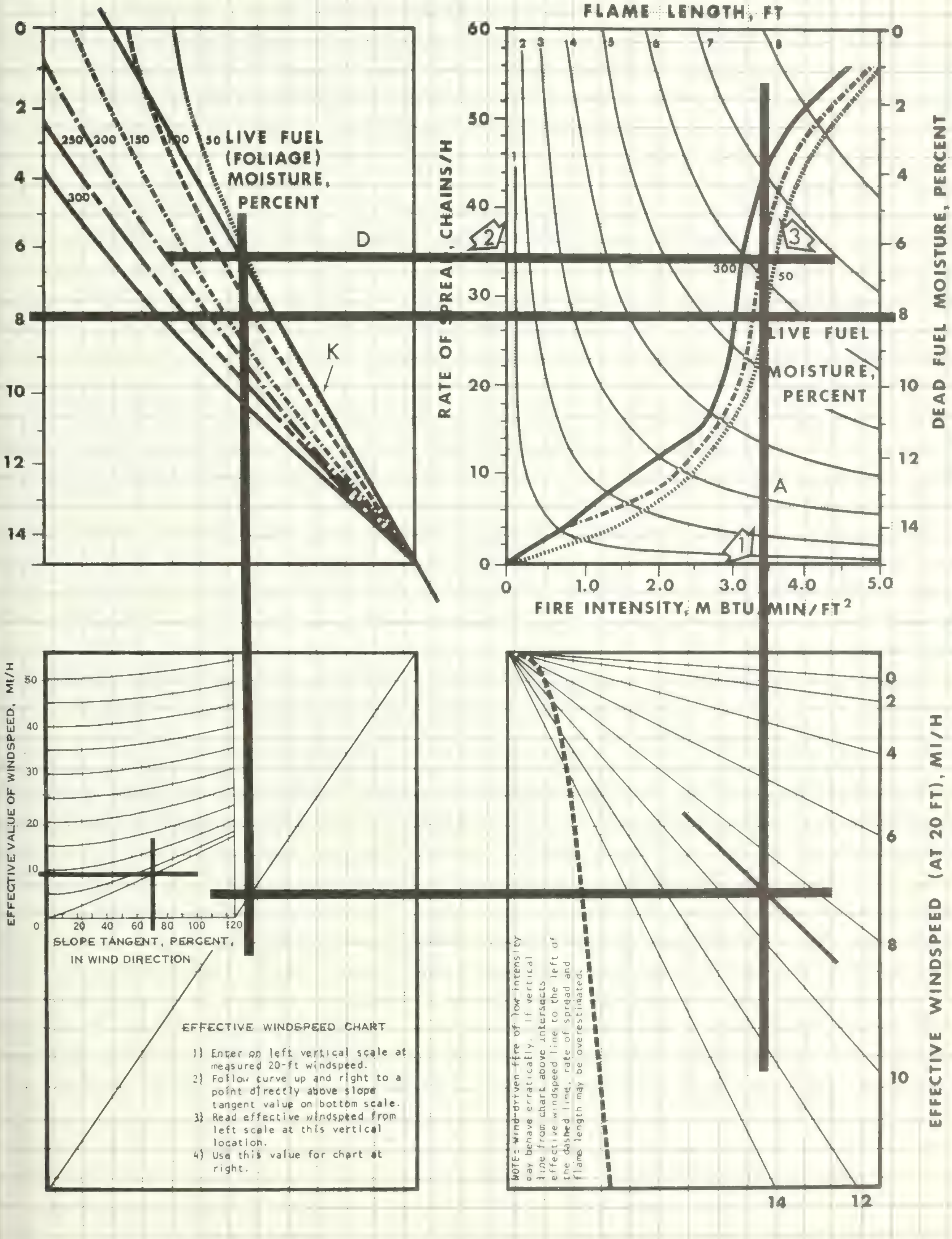
2. TIMBER (GRASS & UNDERSTORY) - LOW WINDSPEEDS

Ex 2D



2. TIMBER (GRASS & UNDERSTORY) - LOW WINDSPEEDS

Ex 2 E



Fire Behavior Estimation Charts

Chart Numbers	*General Fuel Description*
1 - 3	Grass and Grass-Dominated Complexes
4 - 7	Chaparral and Shrubfields
8 - 10	Timber Litter
11 - 13	Logging Slash

These charts are based on stylized "typical" fuel models, much like those used in the National Fire-Danger Rating System, but with some important differences. Estimates made from these charts are not intended to be precise, but rather to provide rough estimates for planning and hazard assessment purposes. The fuel complex descriptions are given in detail in table 7, appendix III.

Fire Behavior Estimation Charts for Grass and Grass-Dominated Complexes

1. Short Grass (1 ft)

   Best fits: Western grasslands, not grazed.

   Also use for: Western savannah types, stubble, grass tundra.

   NOTE: Cured fuels only.

2. Timber (Grass and Understory)

   Best fits: Open pine grassy understory, wiregrass/scrub oak associations.

   Also use for: Timber/sagebrush/grass associations, southern pine clearcut slash.

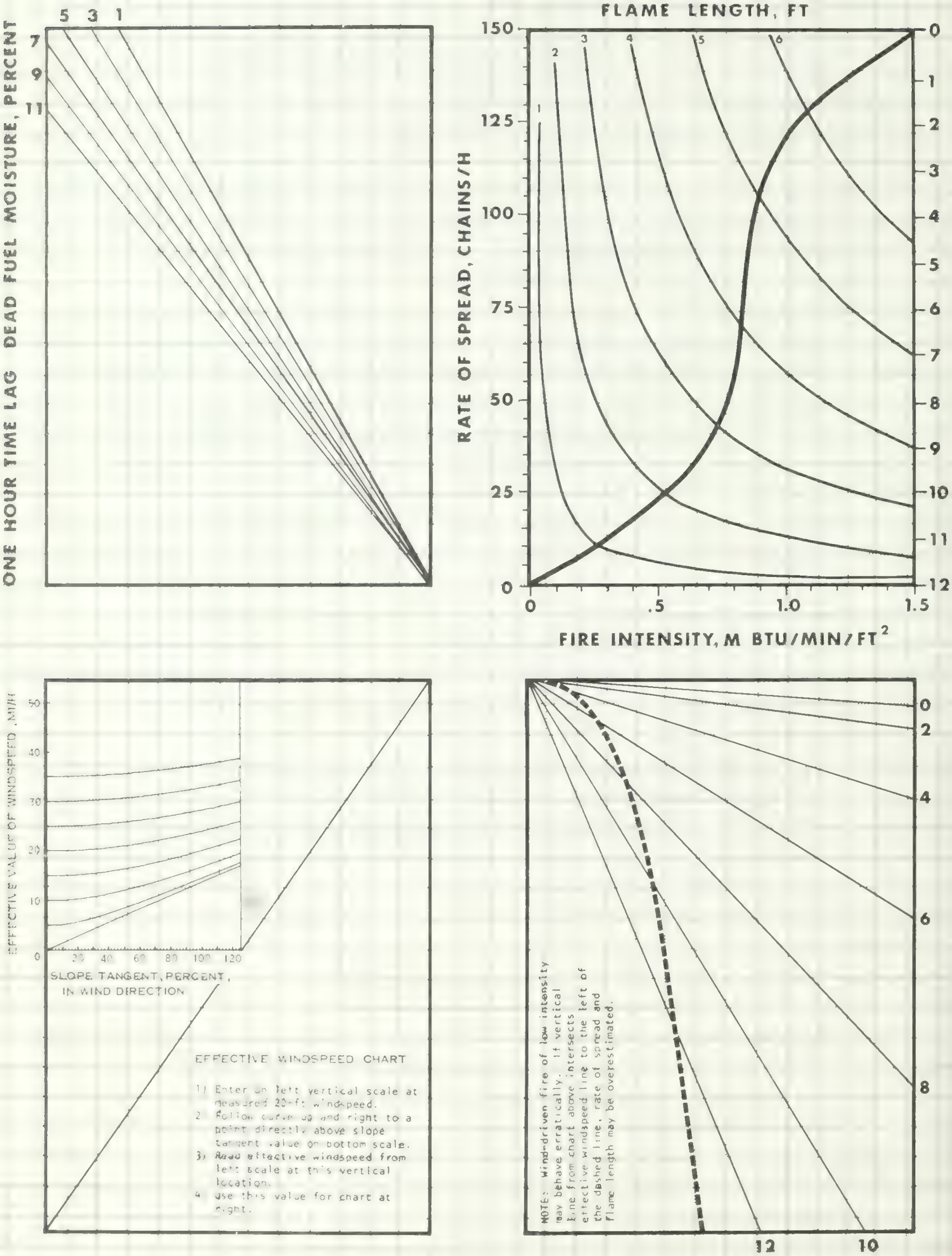
3. Tall Grass (2.5 ft)

   Best fits: Bluebunch wheatgrass, bluestems, galleta, Indiangrass, broomsedge, switchgrass, pineland three-awn, panicgrass, etc.

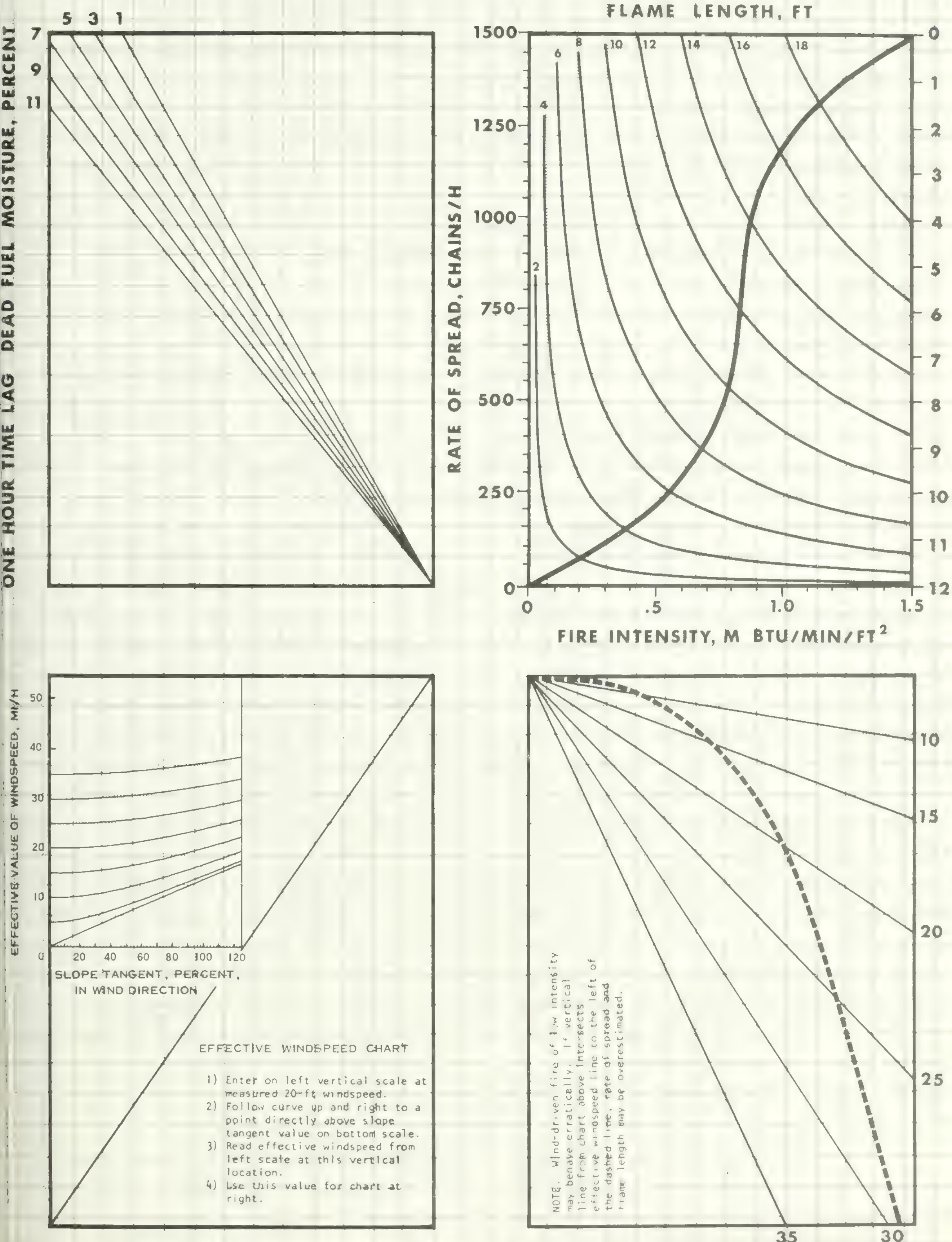
   Also use for: Wild or cultivated grains (cured, not harvested), tall sawgrass, eastern marsh vegetation.

   NOTE: Cured fuels only.

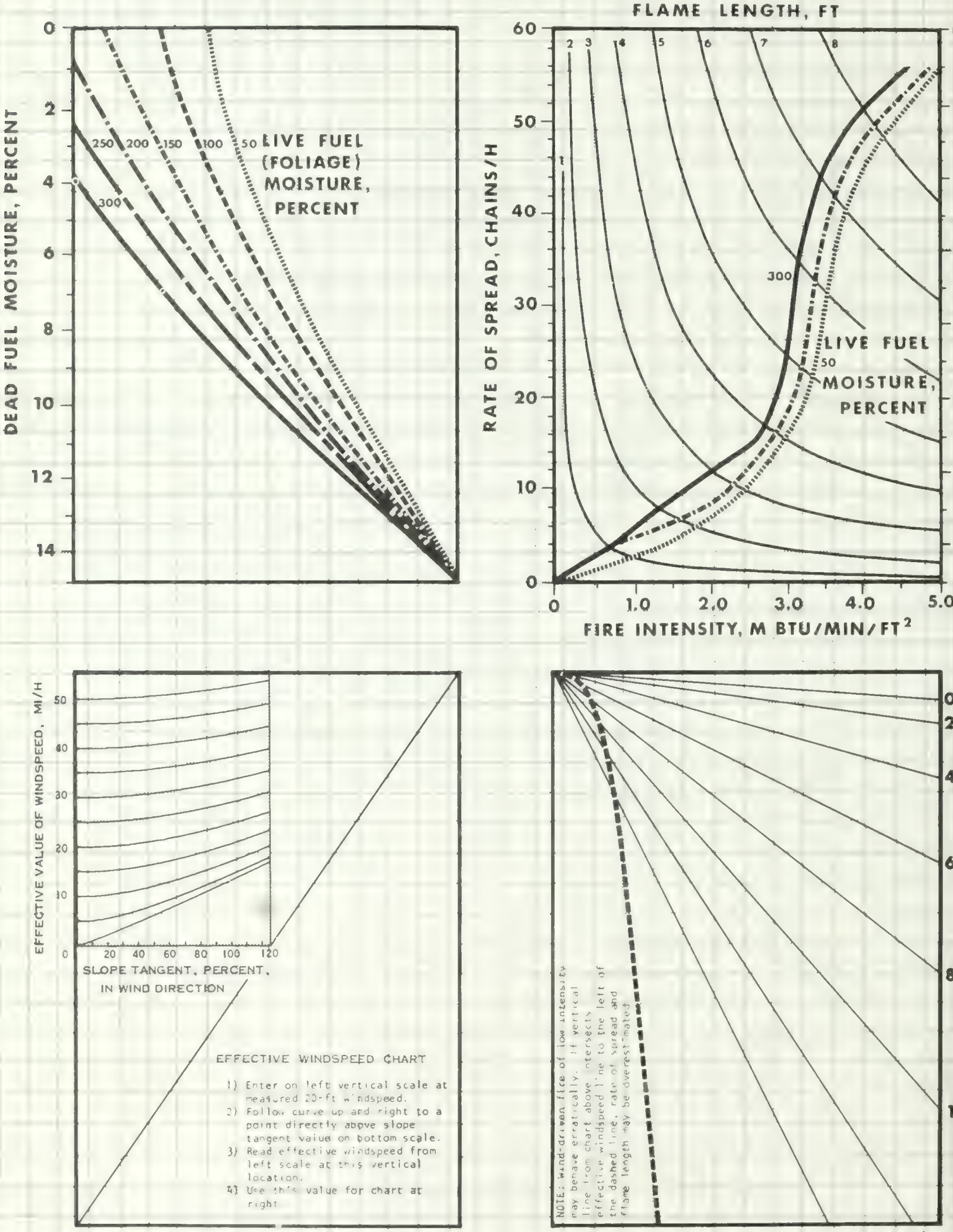
1. SHORT GRASS (1 FT) – LOW WINDSPEEDS



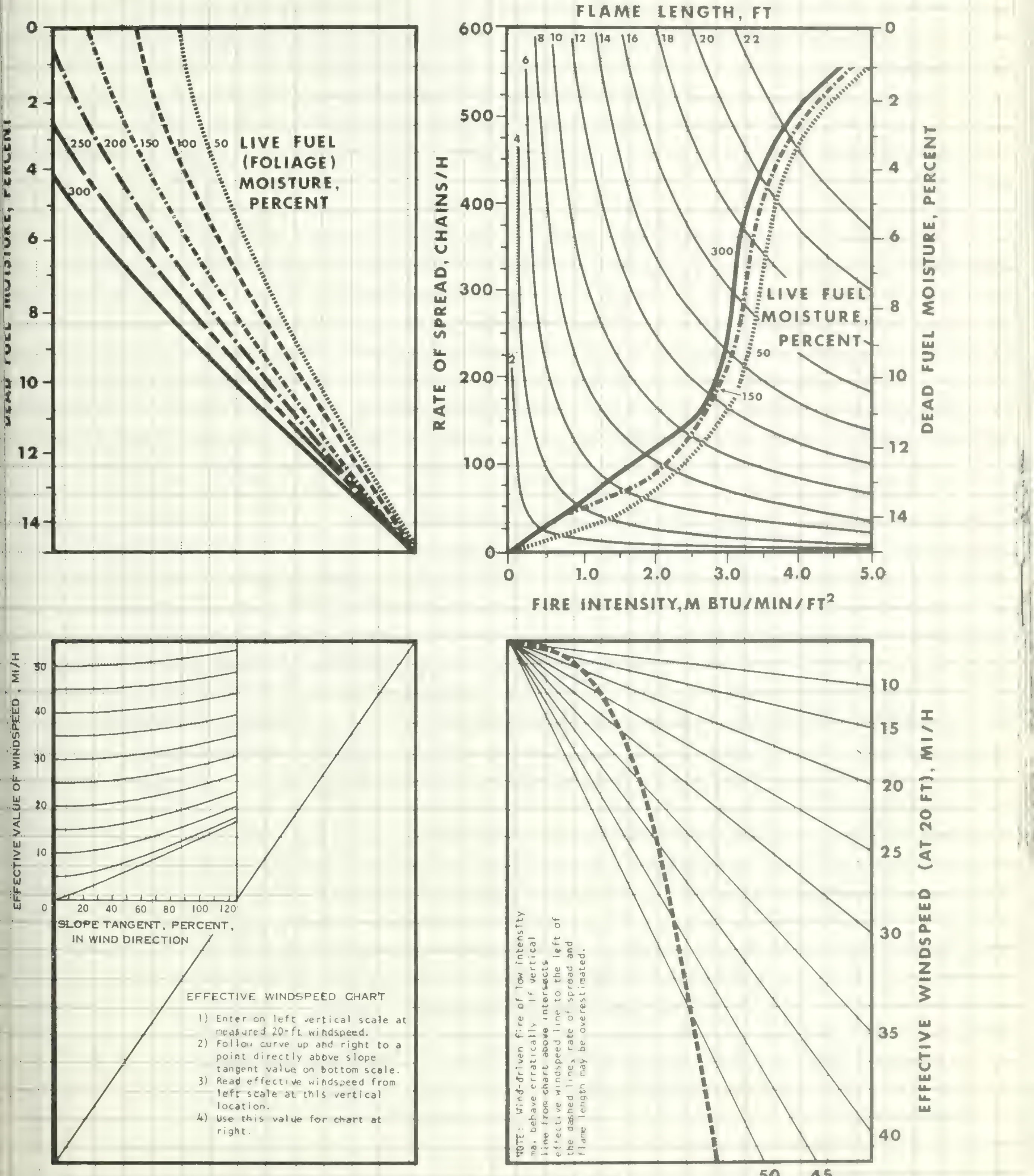
1. SHORT GRASS(1 FT) - HIGH WINDSPEEDS



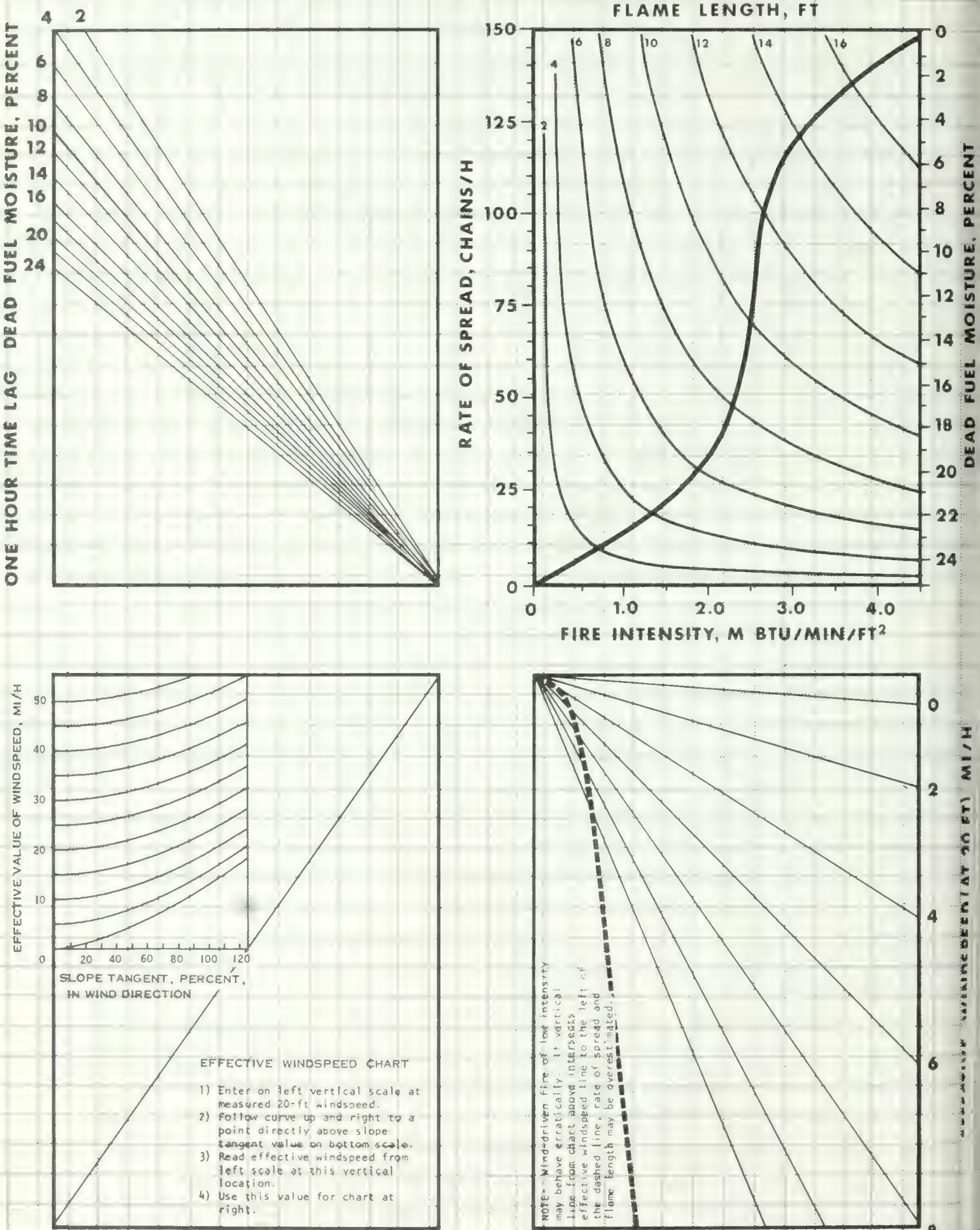
2. TIMBER (GRASS & UNDERSTORY) - LOW WINDSPEEDS



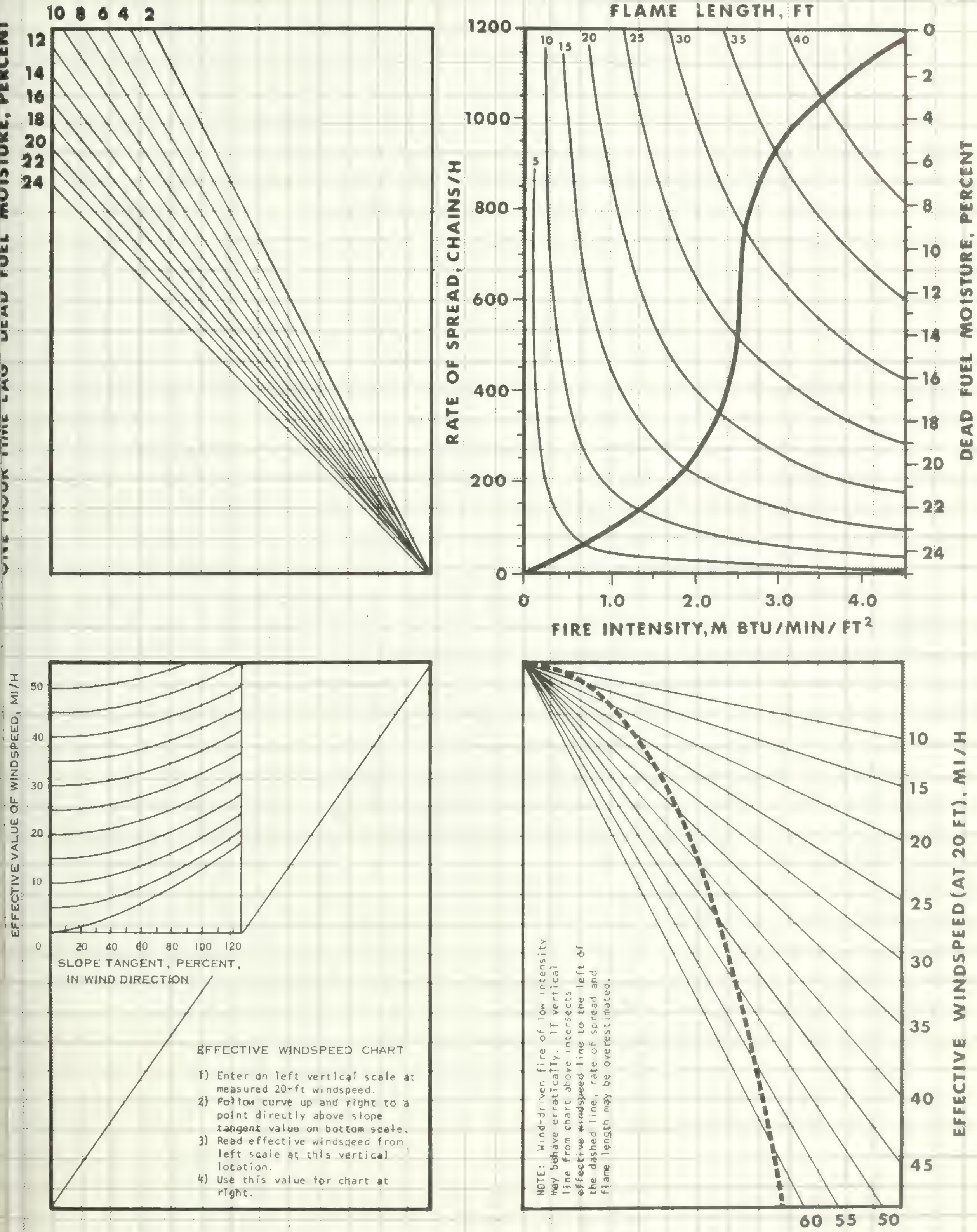
2. TIMBER (GRASS & UNDERSTORY) - HIGH WINDSPEEDS



3. TALL GRASS (2.5 FT) - LOW WINDSPEEDS



3. TALL GRASS (2.5 FT) – HIGH WINDSPEEDS



4. Chaparral (6 ft)

   Best fits: Mature (at least 10 to 15 years old) chaparral, manzanita, chamise.

   Also use for: High pocosins, heavy (more than 120 tons per acre) "red" conifer slash.

5. Brush (2 ft)

   Best fits: Laurel, salal, vine maple, alder, mountain mahogany.

   Also use for: Young chaparral, manzanita, chamise.

6. Dormant Brush, Hardwood Slash

   Best fits: Low pocosins (dormant), Alaskan spruce taiga, shrub tundra.

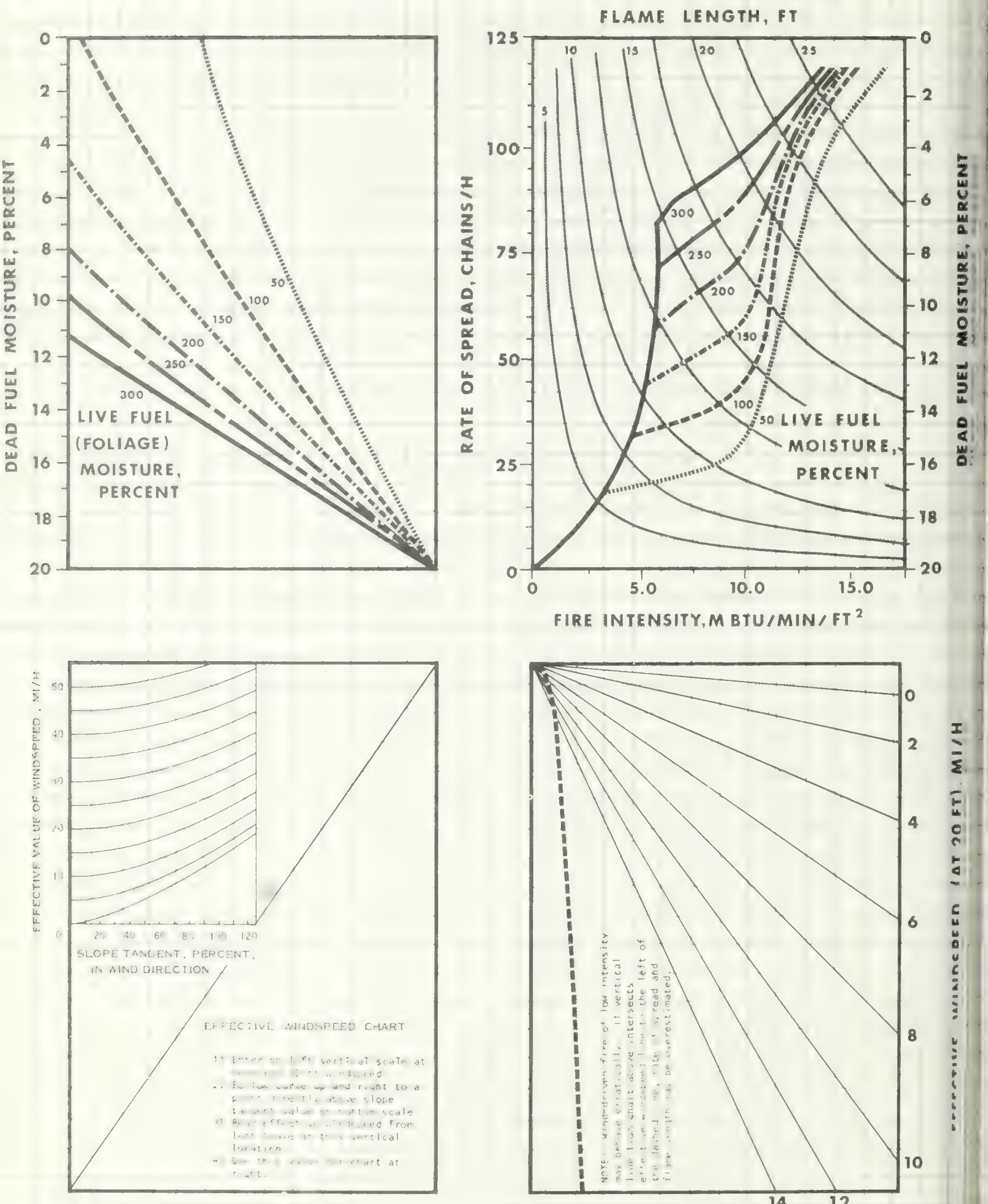
   Also use for: Fresh hardwood logging slash (40 tons per acre or less).

7. Southern Rough

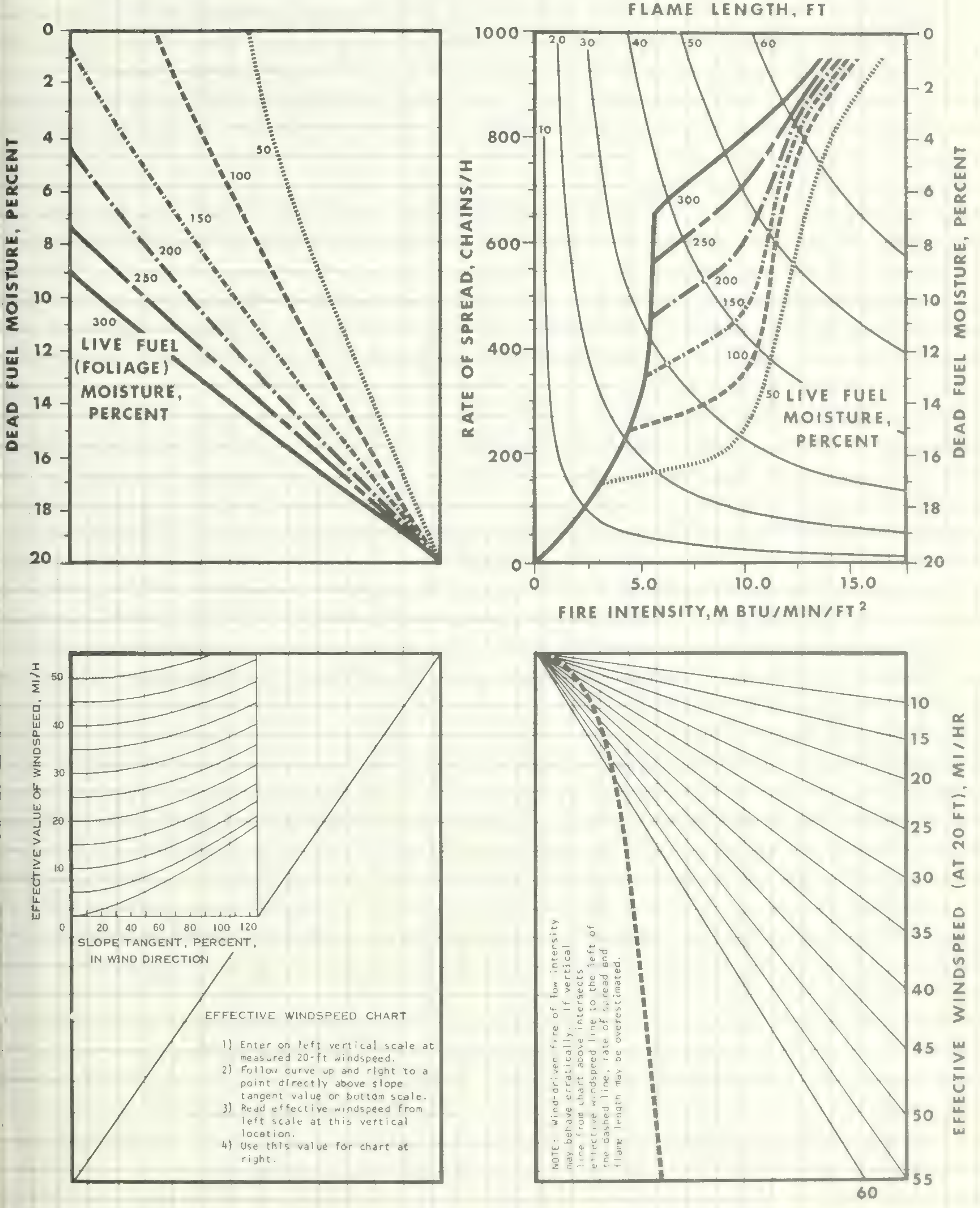
   Best fits: Southern rough (2 years), palmetto-gallberry communities.

   Also use for: Low pocosins (not dormant).

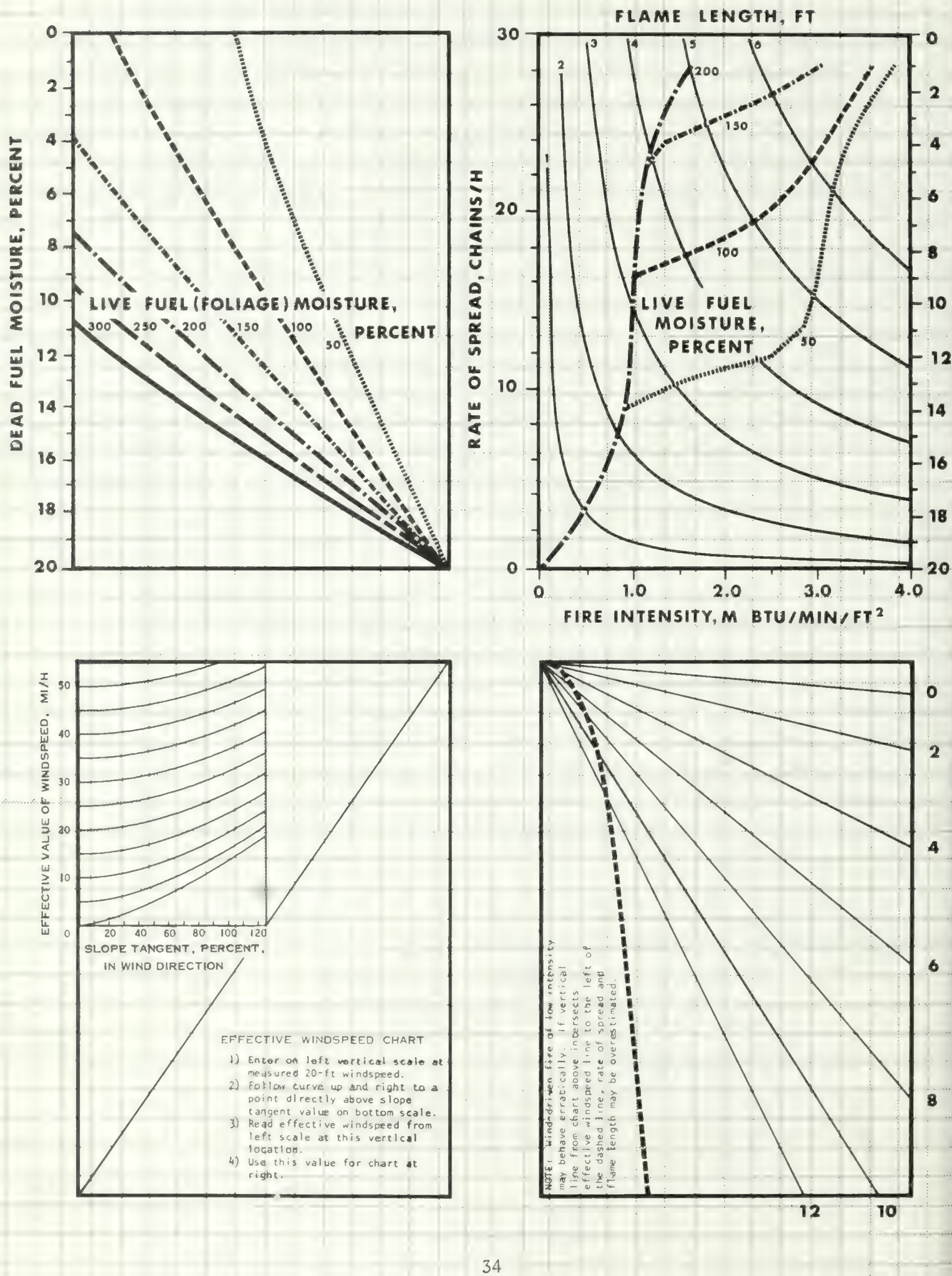
4. CHAPARRAL(6 FT) -LOW WINDSPEEDS



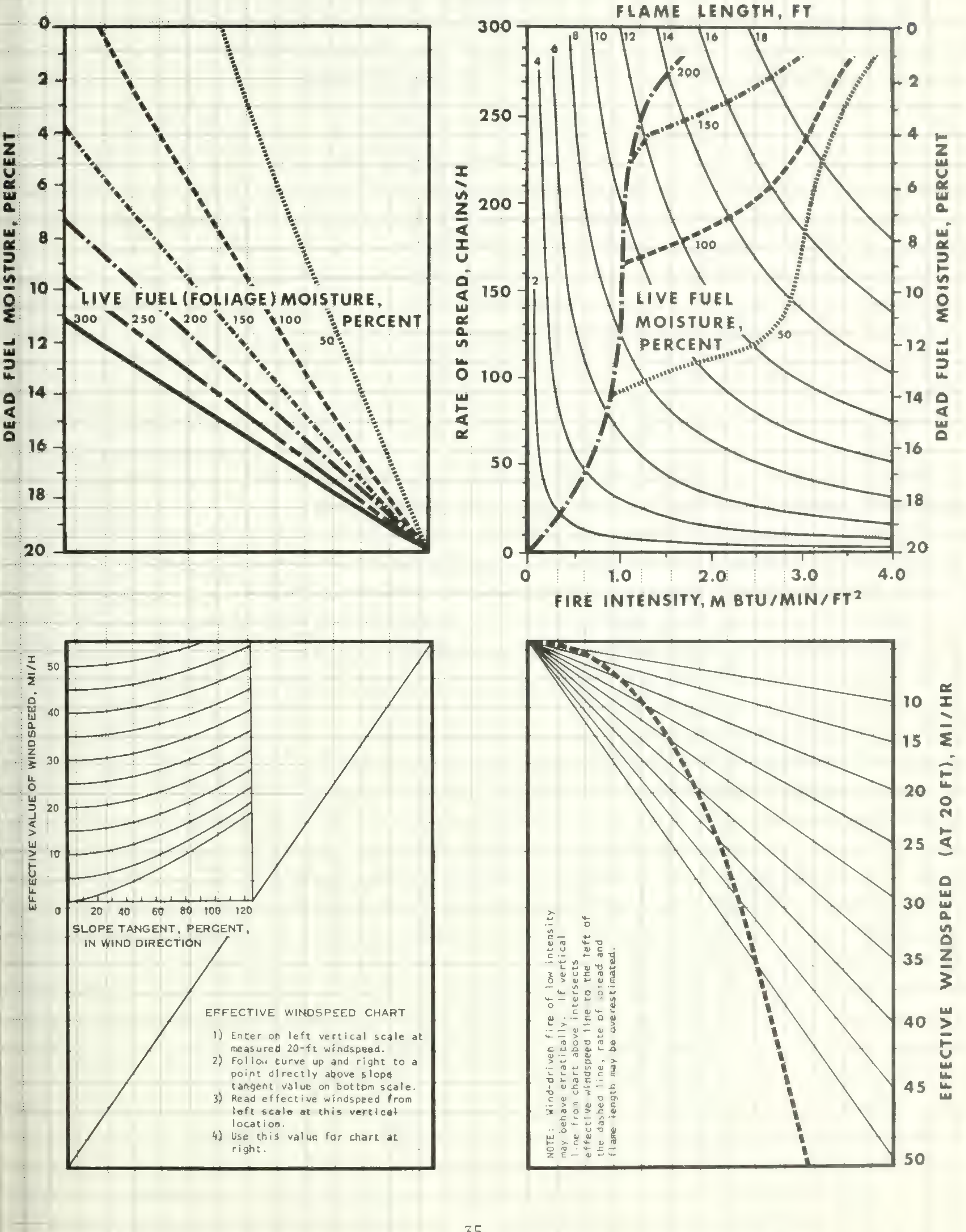
4. CHAPARRAL (6 FT)- HIGH WINDSPEEDS



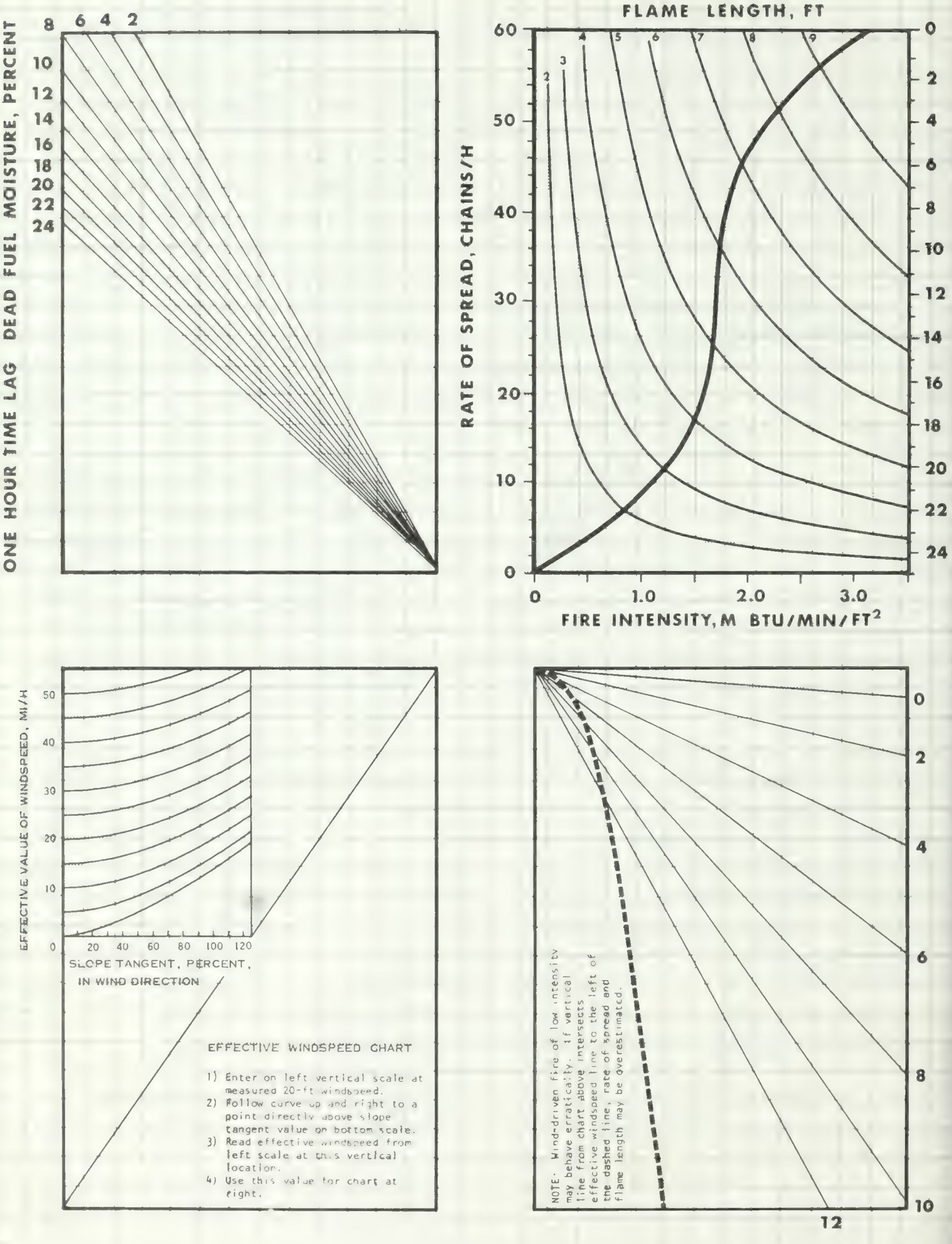
5. BRUSH (2 FT) -LOW WINDSPEEDS



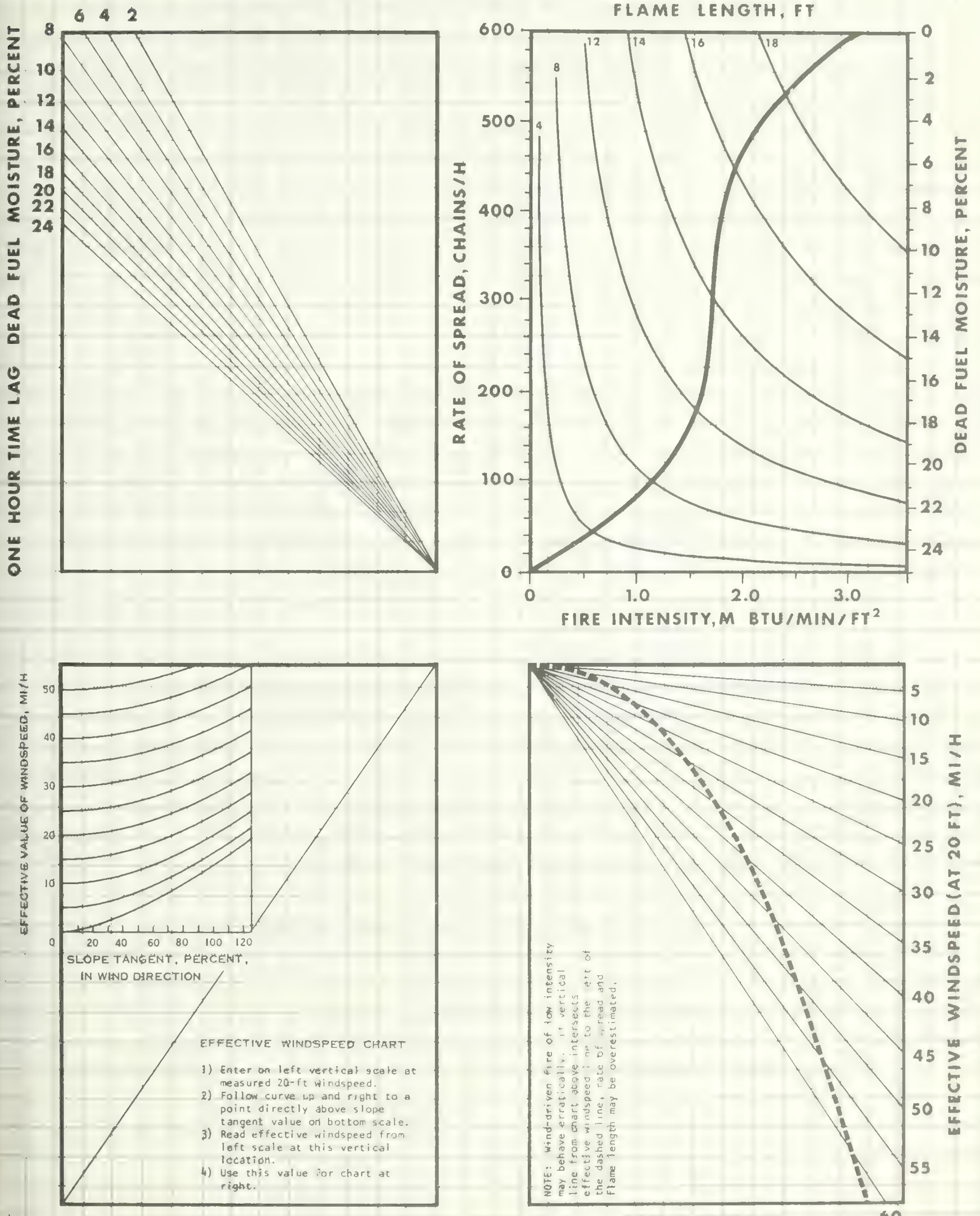
5. BRUSH (2 FT) - HIGH WINDSPEEDS



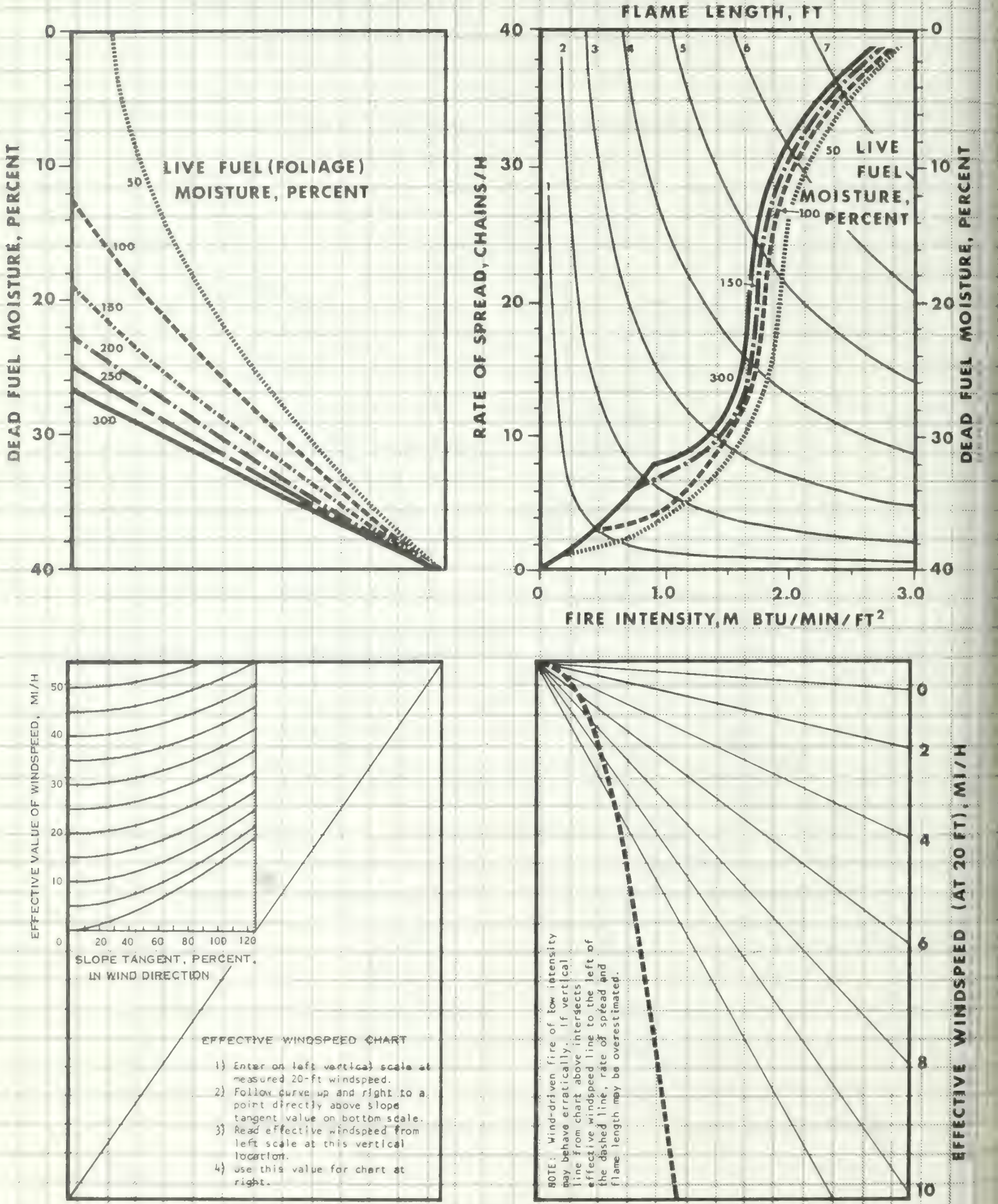
6. DORMANT BRUSH, HARDWOOD SLASH-LOW WINDSPEEDS



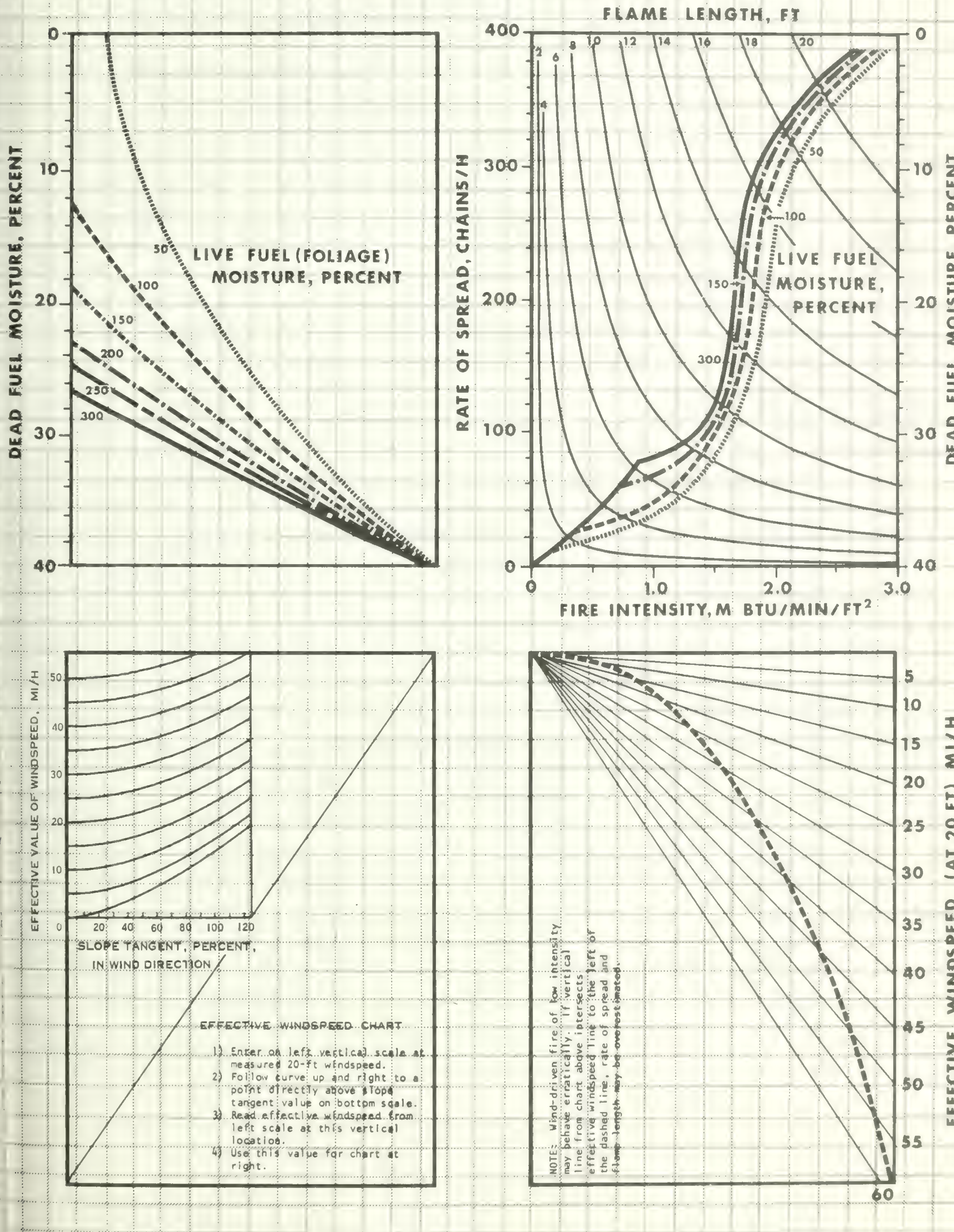
6. DORMANT BRUSH, HARDWOOD SLASH-HIGH WINDSPEEDS



7. SOUTHERN ROUGH - LOW WINDSPEEDS



7. SOUTHERN ROUGH -HIGH WINDSPEEDS



8. Closed Timber Litter

   Best fits: compact litter in closed, short-needle conifer stands.

   Also use for: Compact hardwood litter (see 9 also).

9. Hardwood Litter

   Best fits: Fresh, uncompacted oak/hickory litter.

   Also use for: Fresh, uncompacted litter under maple, tulip poplar, aspen, etc.

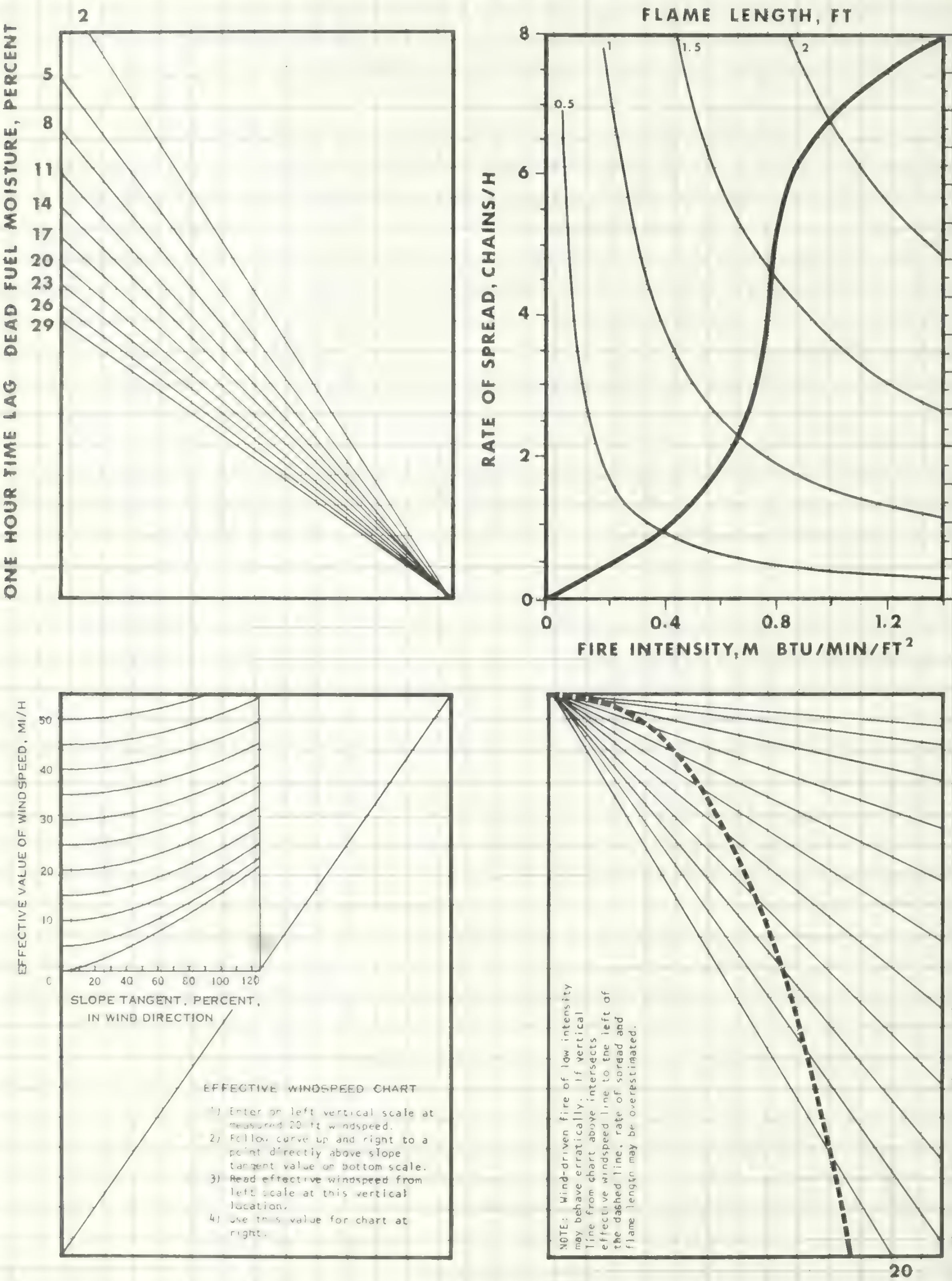
   NOTE: Blown, burning leaves may increase spread rate above chart predictions.

10. Timber (Litter and Understory)

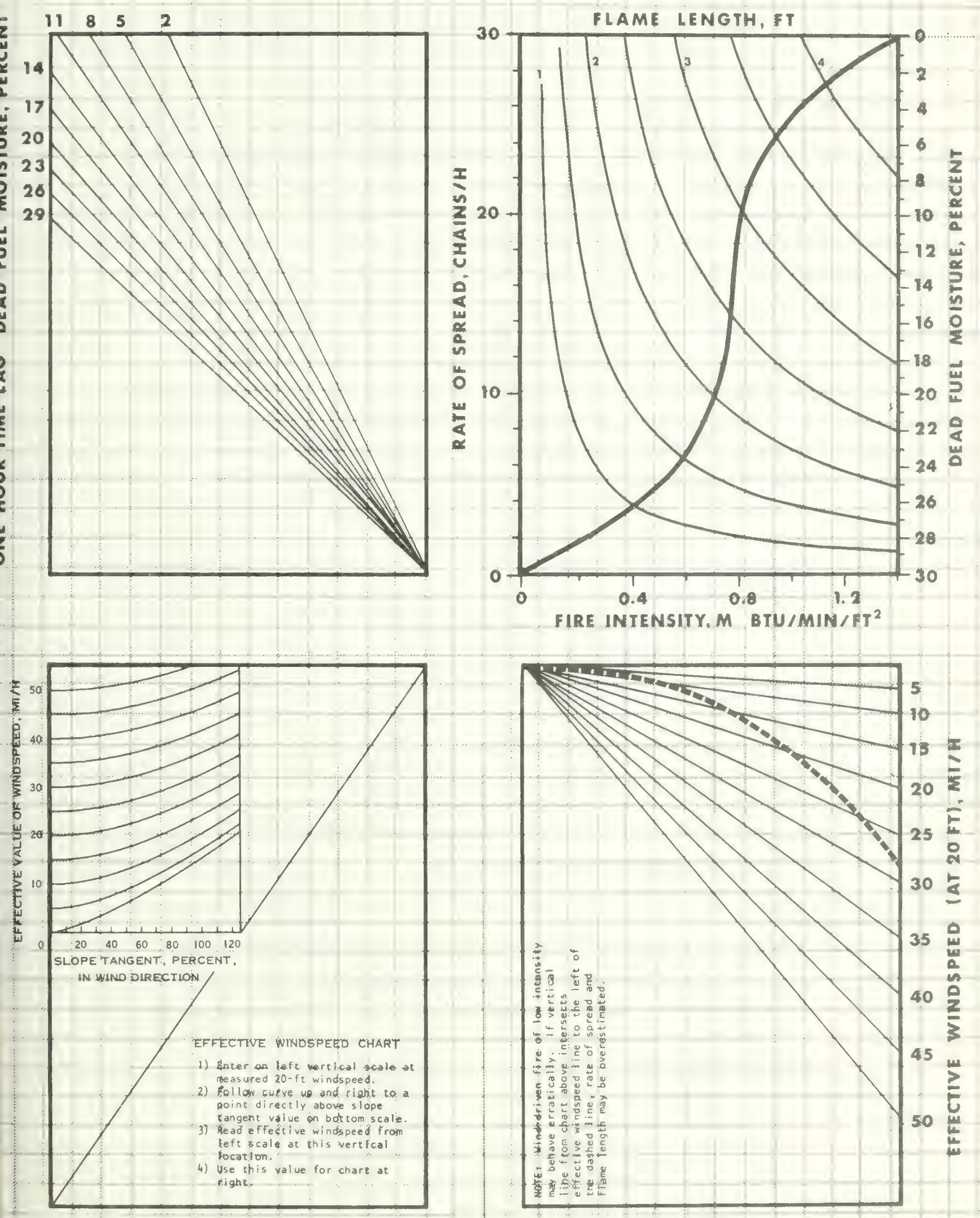
    Best fits: Overmature conifer stands with high loadings of dead, down woody fuel, including shrub understory or conifer reproduction.

    Also use for: Settled thinning or partial-cut conifer slash, with needles fallen, overgrown by shrubs or conifer reproduction.

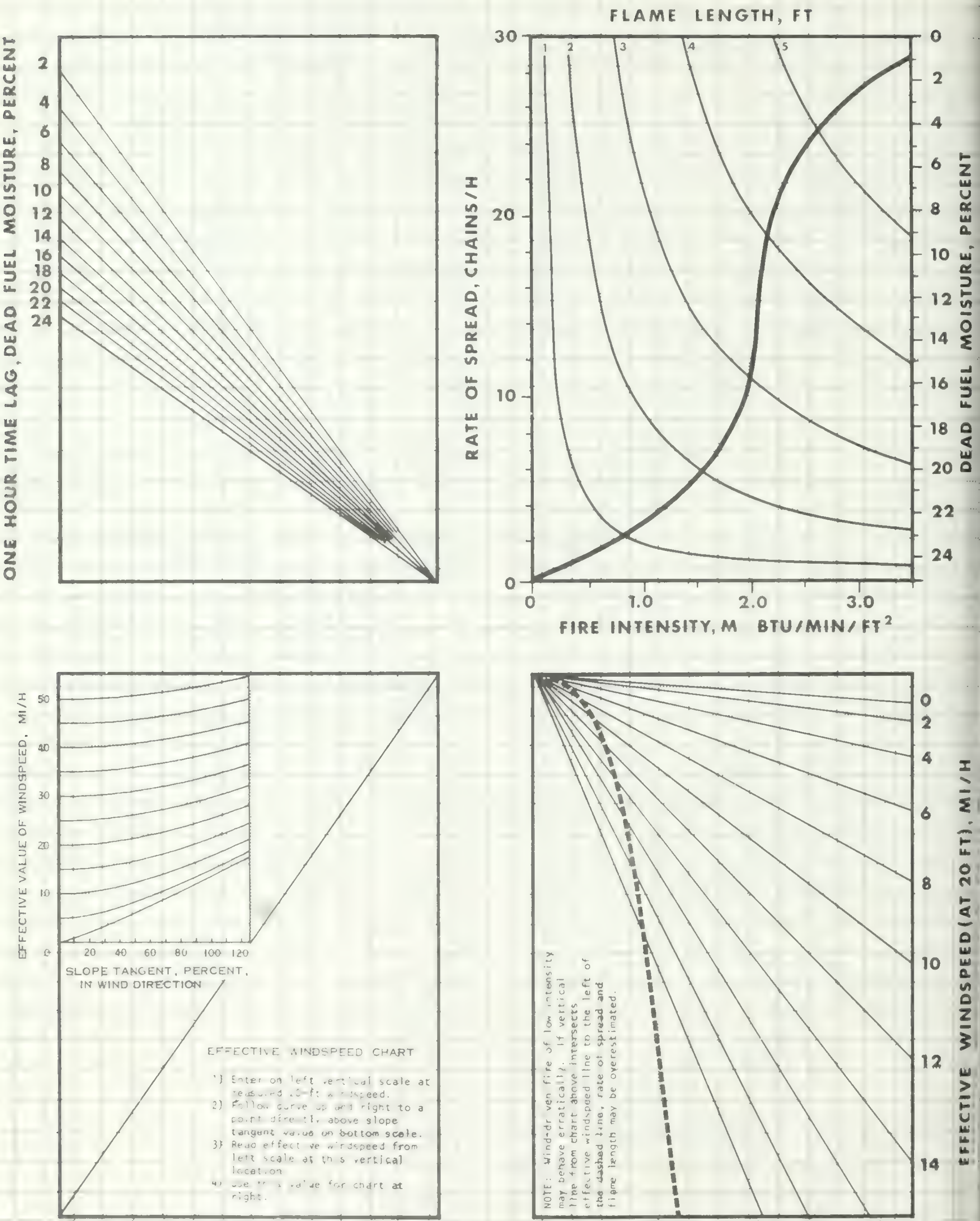
8. CLOSED TIMBER LITTER - LOW WINDSPEEDS



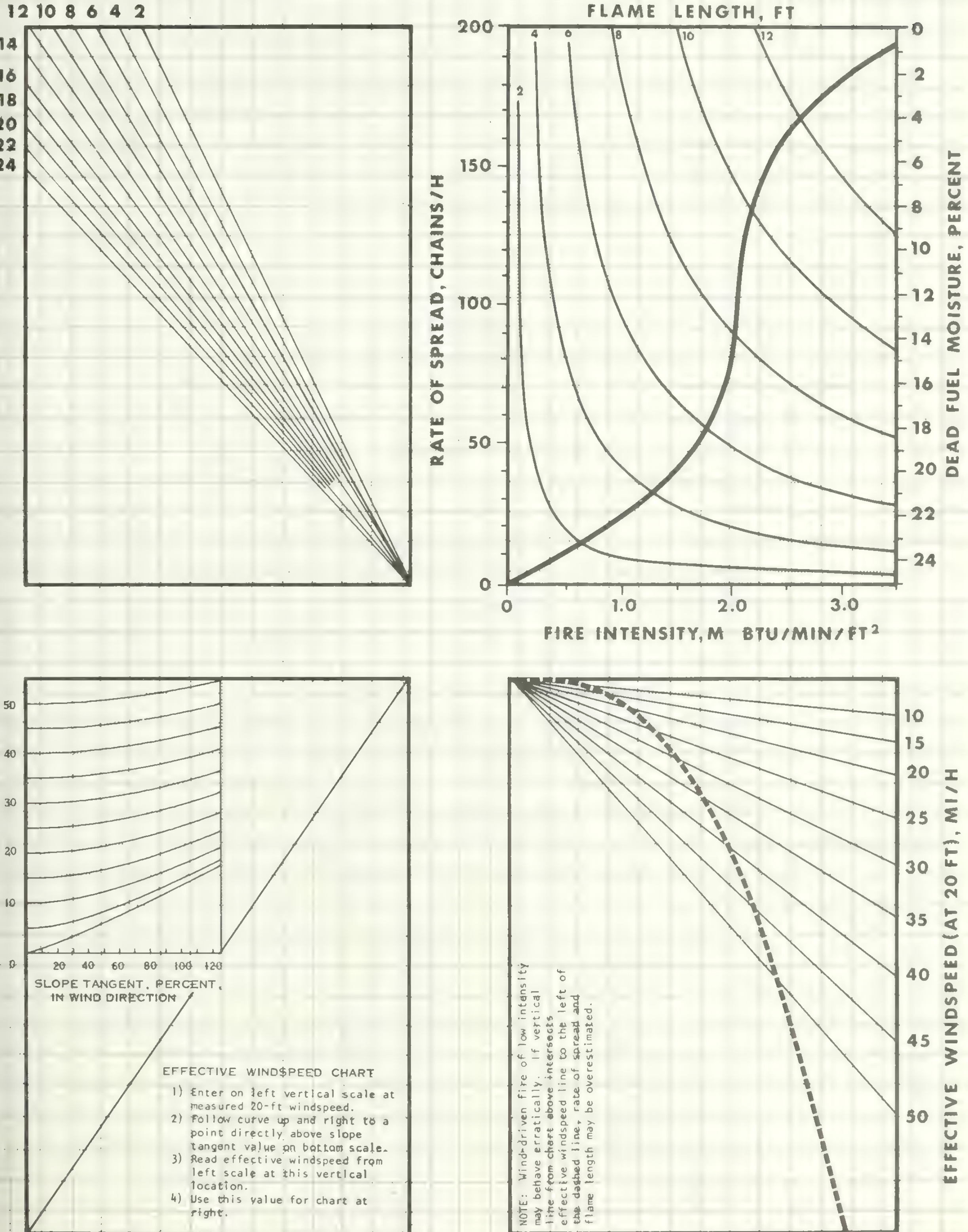
8. CLOSED TIMBER LITTER– HIGH WINDSPEEDS



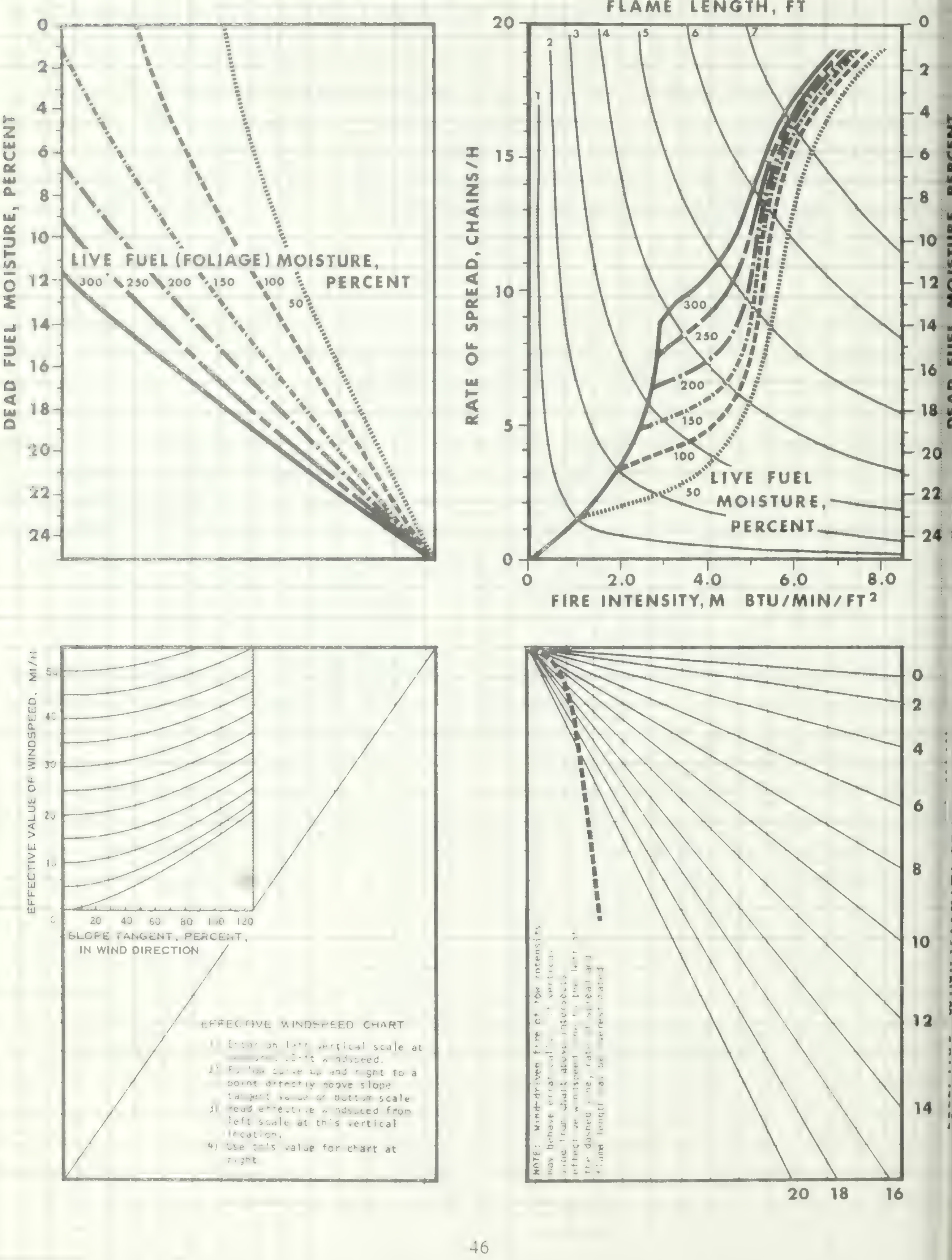
9. HARDWOOD LITTER – LOW WINDSPEEDS



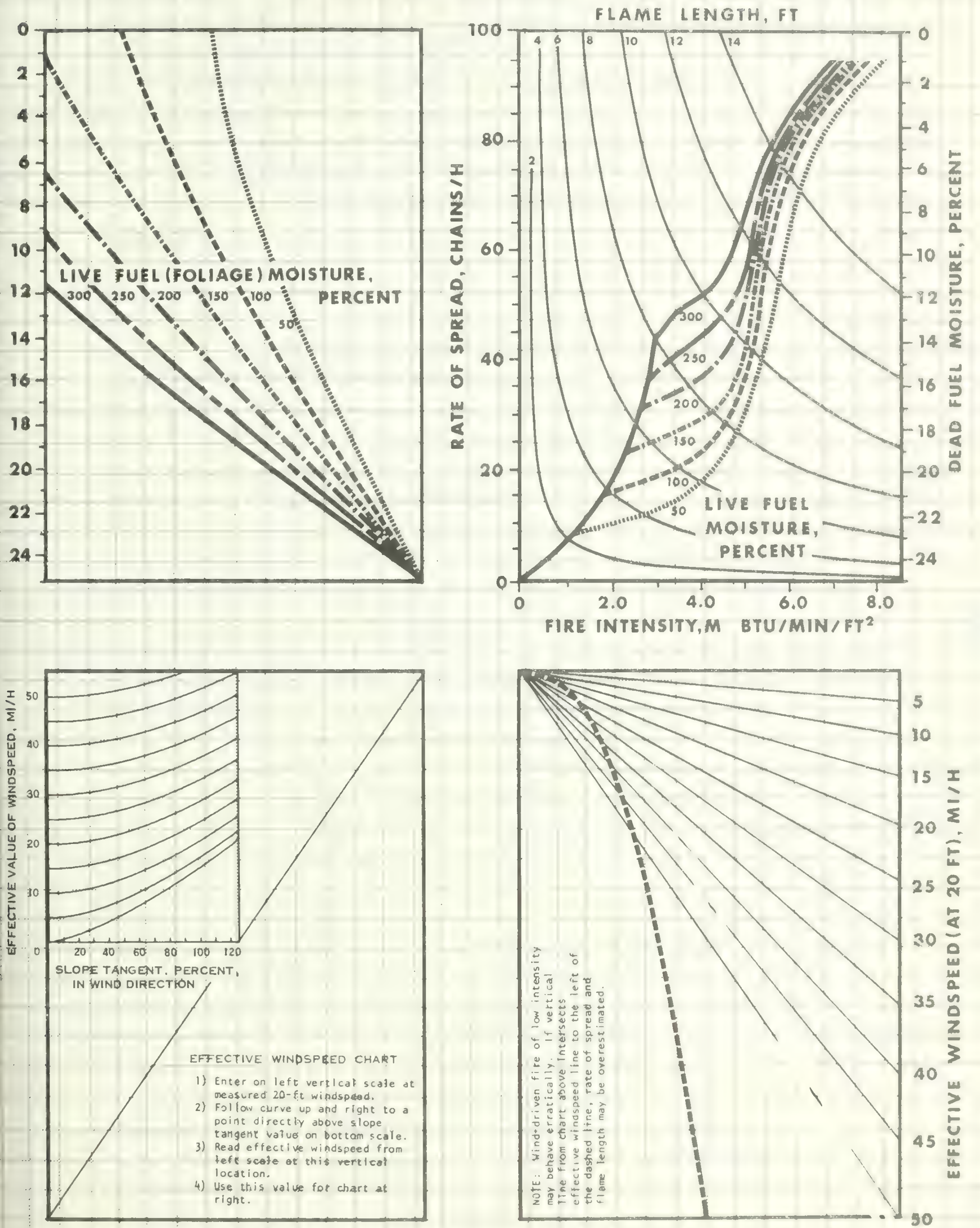
9. HARDWOOD LITTER-HIGH WINDSPEEDS



10. TIMBER (LITTER & UNDERSTORY)-LOW WINDSPEEDS



10. TIMBER (LITTER & UNDERSTORY)-HIGH WINDSPEEDS



11. Light Logging Slash

Best fits: Light (under 40 tons per acre) logging slash from partial or clearcut western mixed conifers. Most needles have fallen, slash somewhat compact.

12. Medium Logging Slash

Best fits: Medium (40 to 120 tons per acre) logging slash from clearcut western mixed conifers. Most needles have fallen, slash somewhat compact.

Also use for: Light "red" slash, with needles attached.

13. Heavy Logging Slash

Best fits: Heavy (more than 120 tons per acre) logging slash from clearcut western mixed conifers. Most needles have fallen, slash somewhat compact.

Also use for: Medium "red" slash, with needles attached.

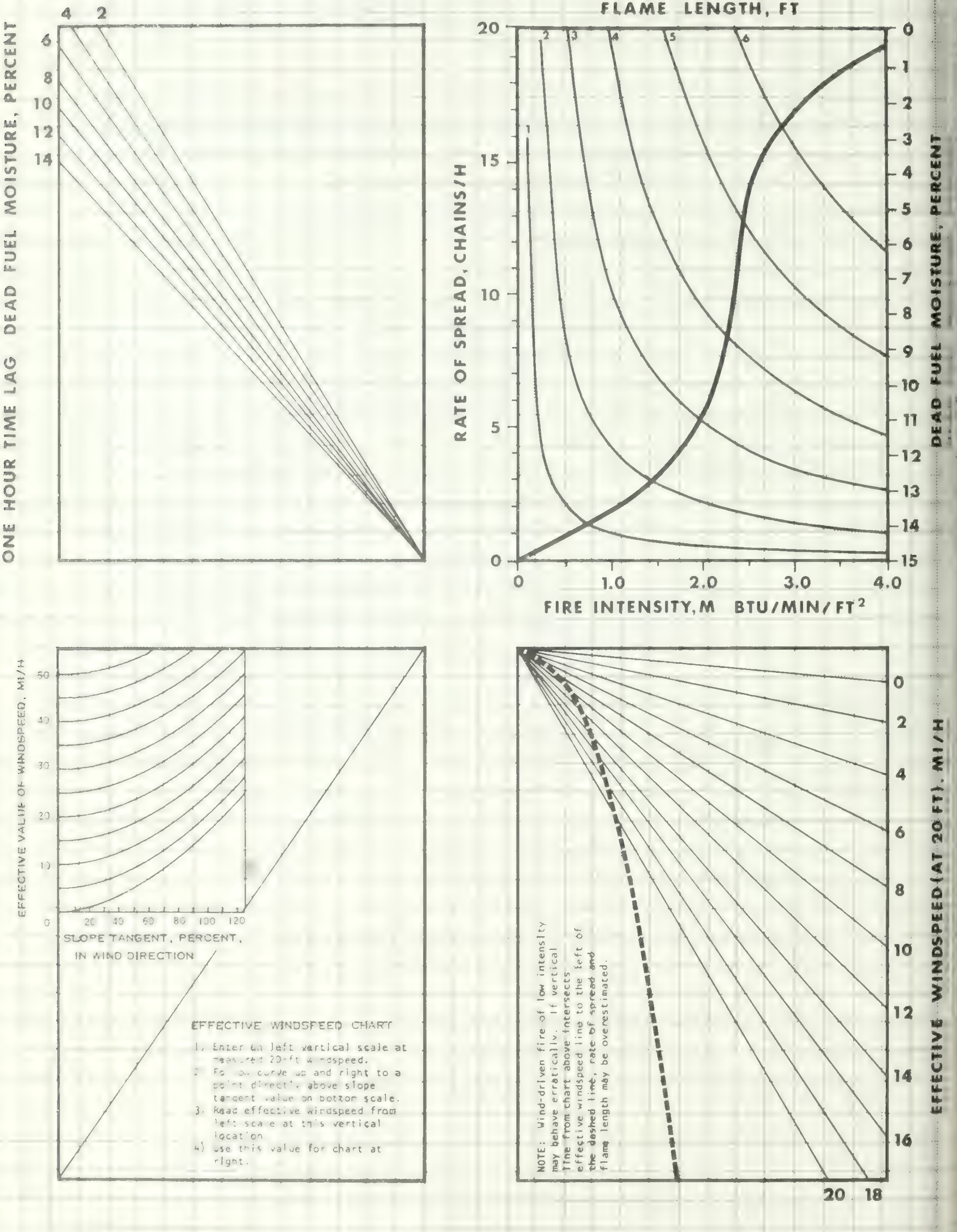
NOTES: Hardwood slash - see model 6

Heavy "red" slash - see model 4

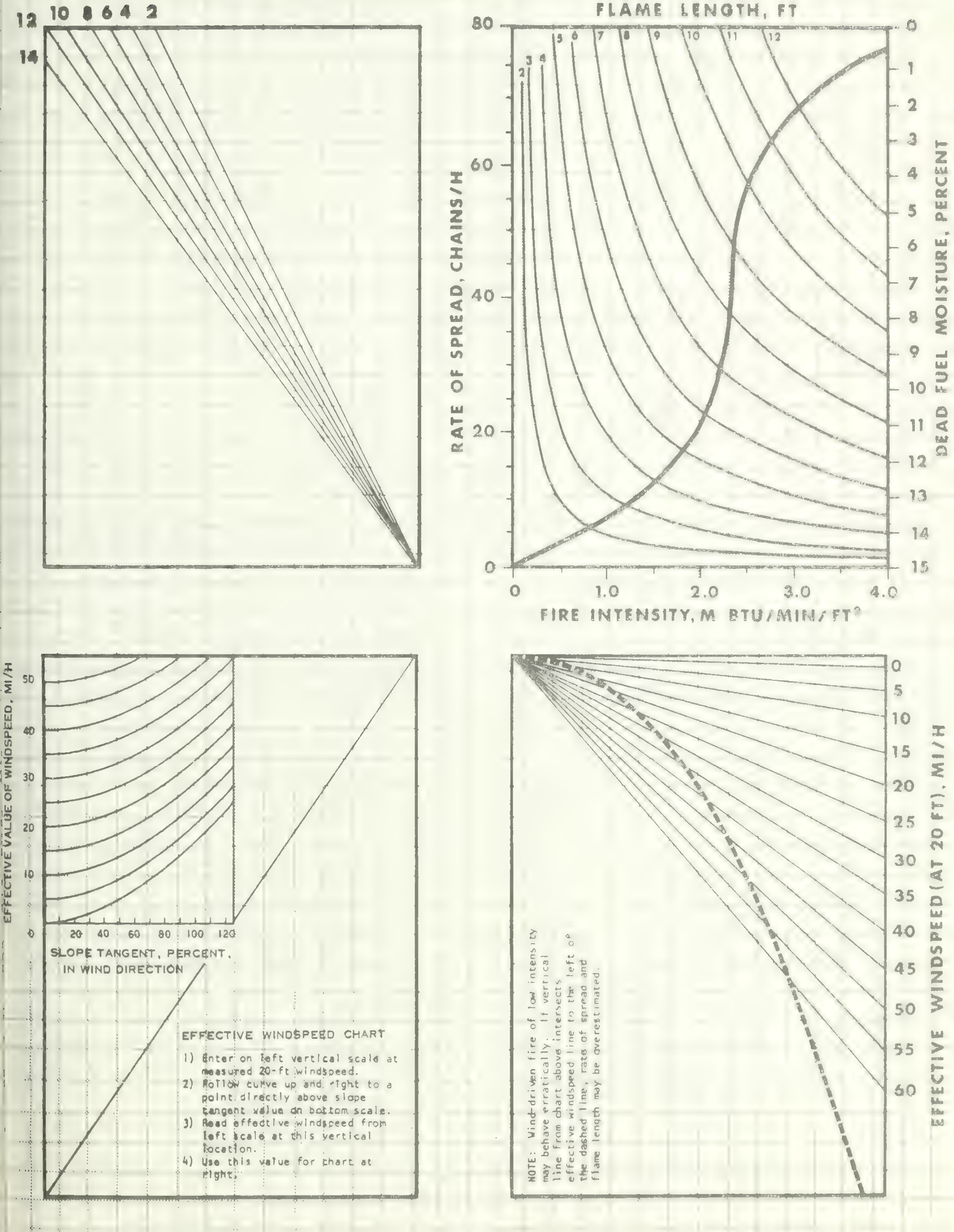
Overgrown slash - see model 10

Southern pine clearcut slash - see model 2

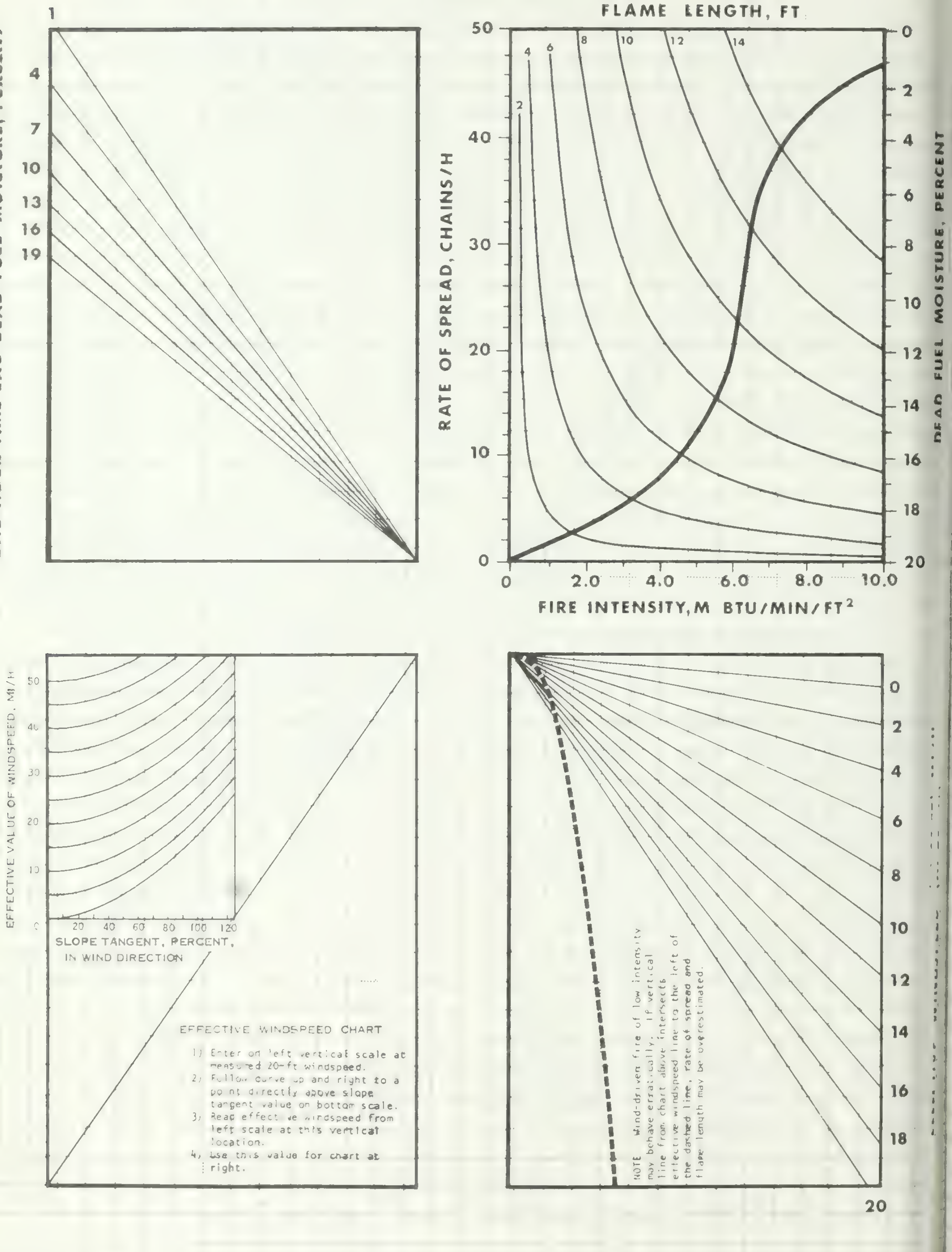
11. LIGHT LOGGING SLASH–LOW WINDSPEEDS



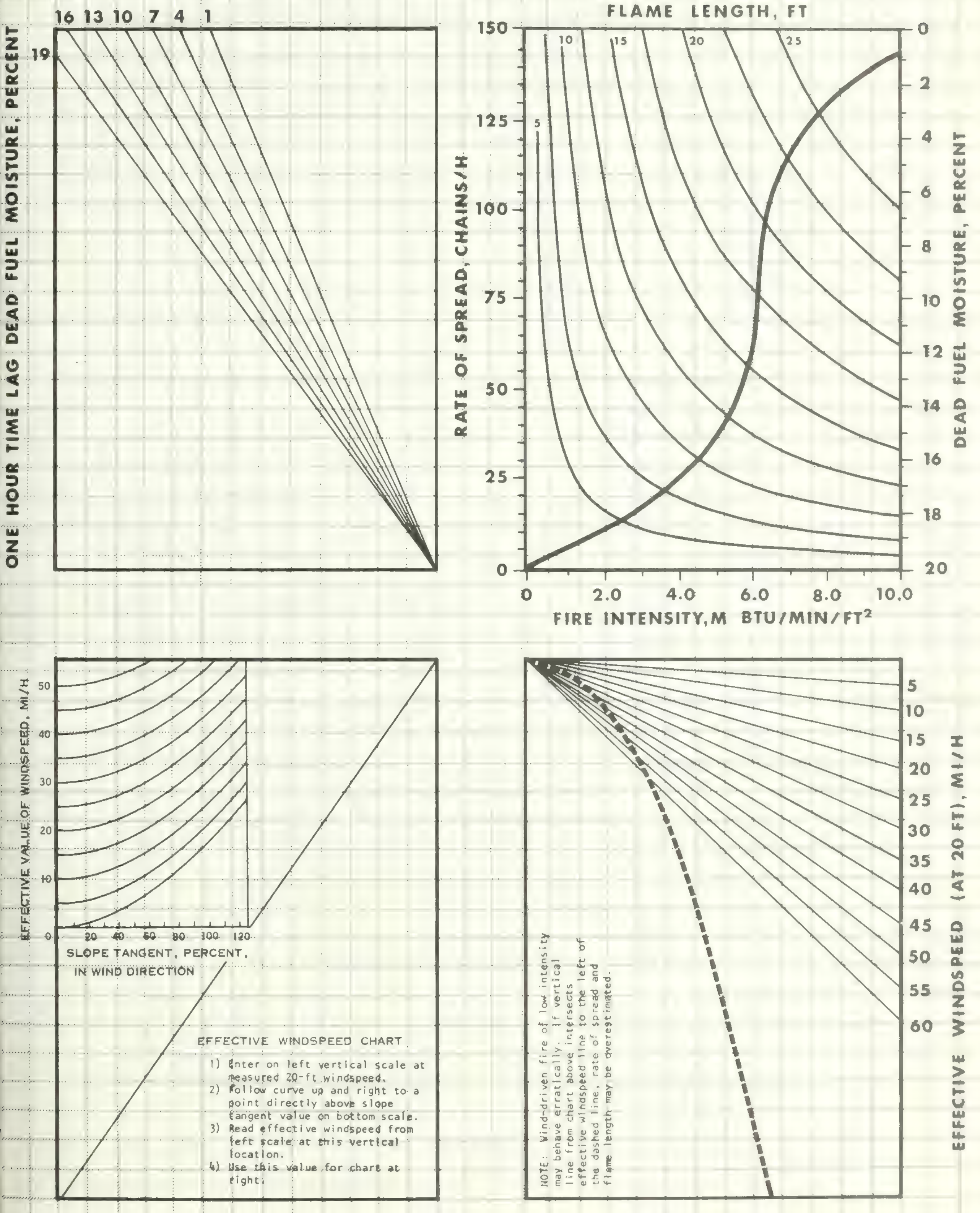
11. LIGHT LOGGING SLASH-HIGH WINDSPEEDS



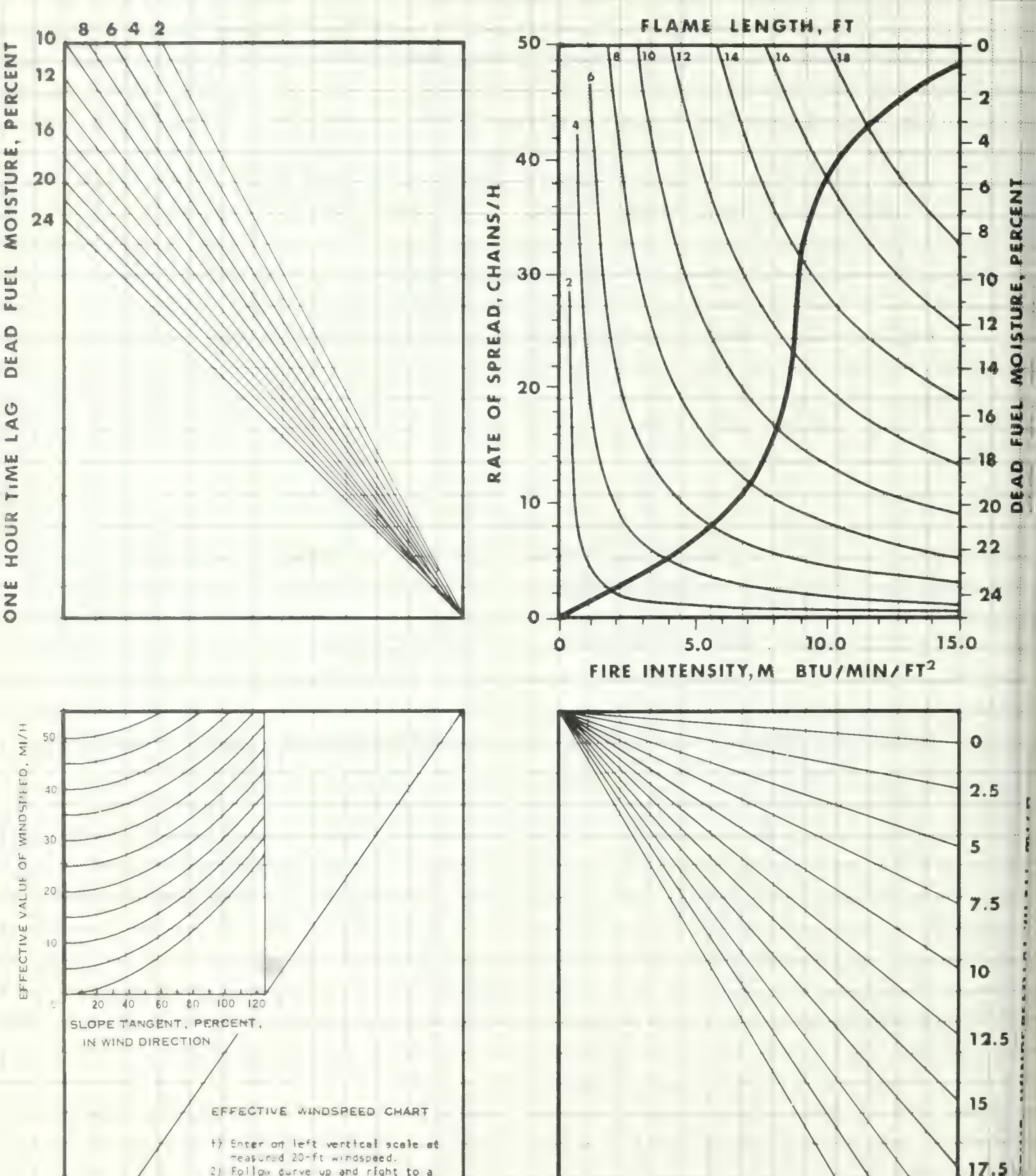
12. MEDIUM LOGGING SLASH – LOW WINDSPEEDS



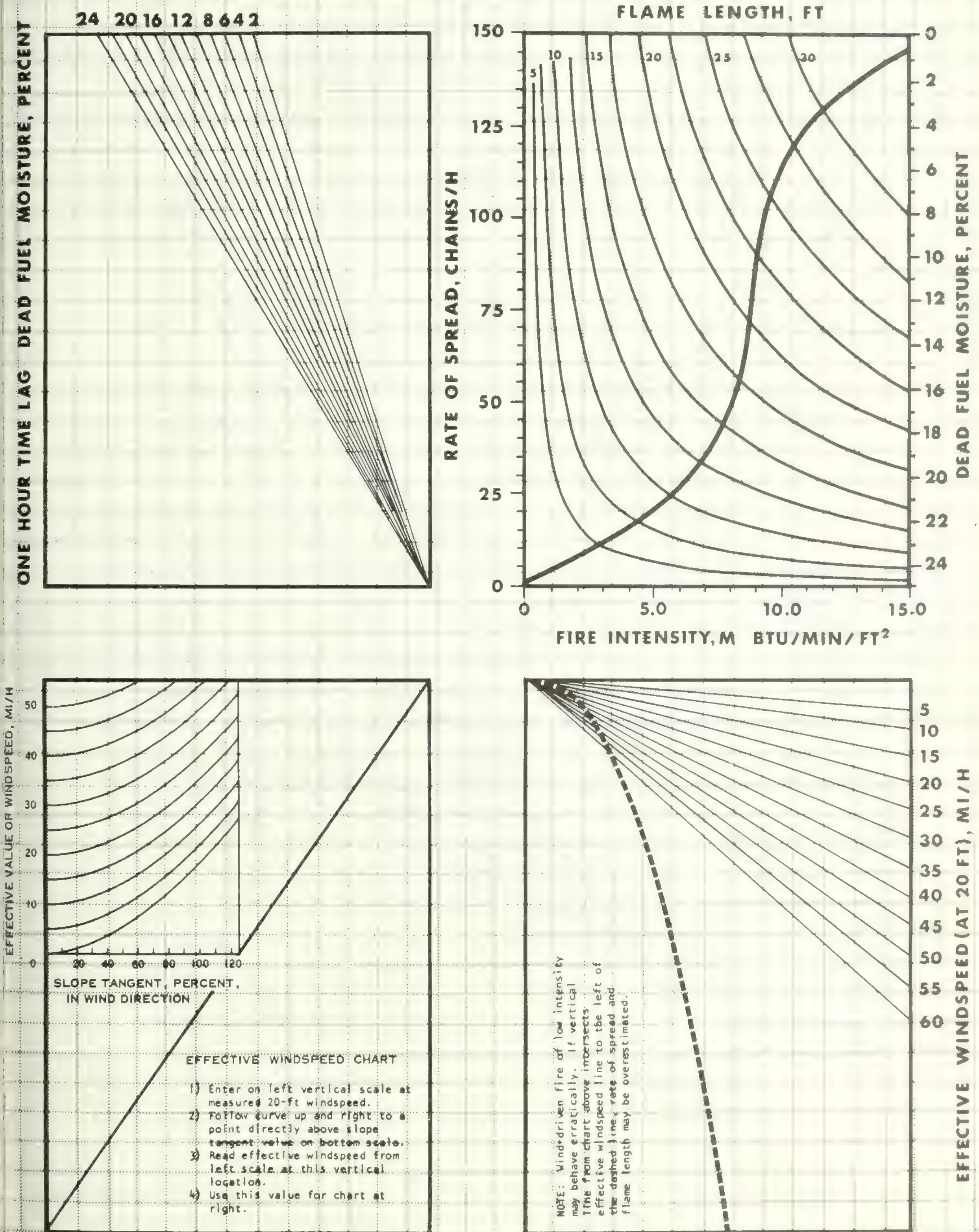
12. MEDIUM LOGGING SLASH-HIGH WINDSPEEDS



13. HEAVY LOGGING SLASH-LOW WINDSPEEDS



13. HEAVY LOGGING SLASH-HIGH WINDSPEEDS



Effects of Wind and Slope on Forward Rate of Spread

The computer-based versions of Rothermel's spread model and the nomographs pre sented above allow one to incorporate the effects of wind and slope, either separat or combined. The stylized fuel models were used to establish the fuel bed properti which influence spread rate sensitivity to wind and slope (appendix II), shown in figures 3 and 4. These figures provide estimates of the effects of slope or wind o a fire burning in a fuel that resembles one of the 13 stylized models used here.

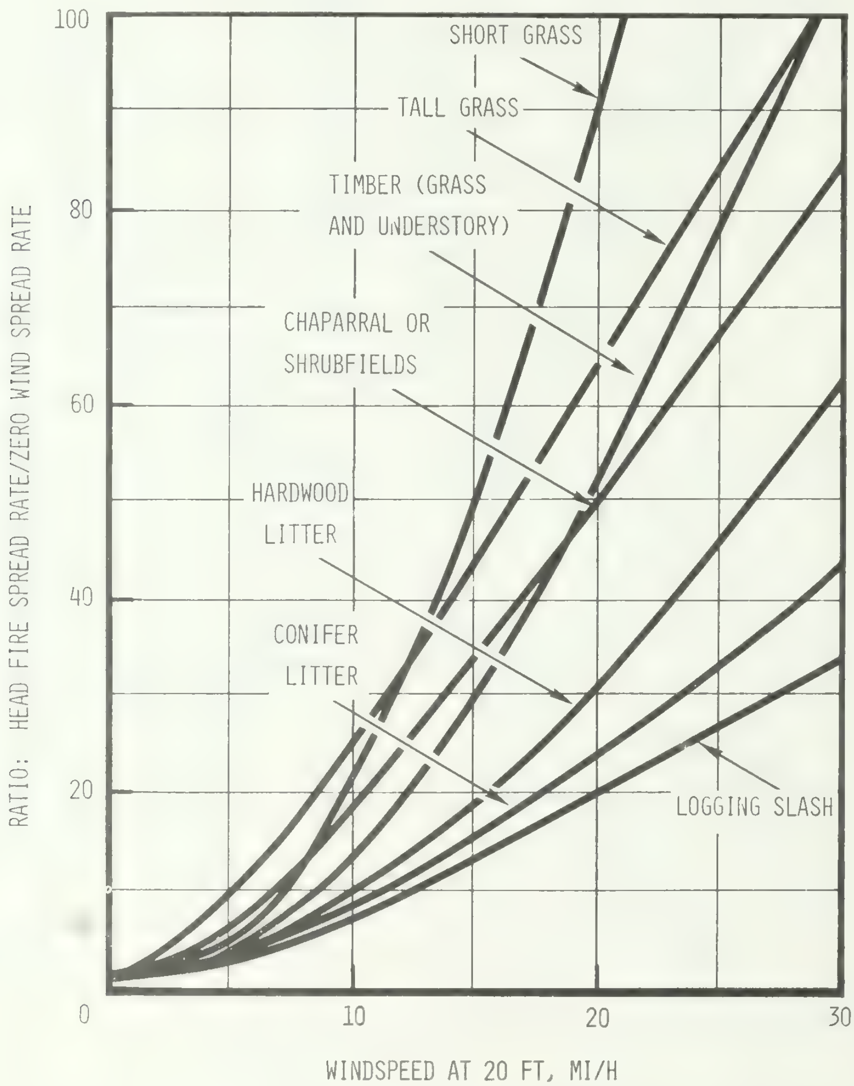
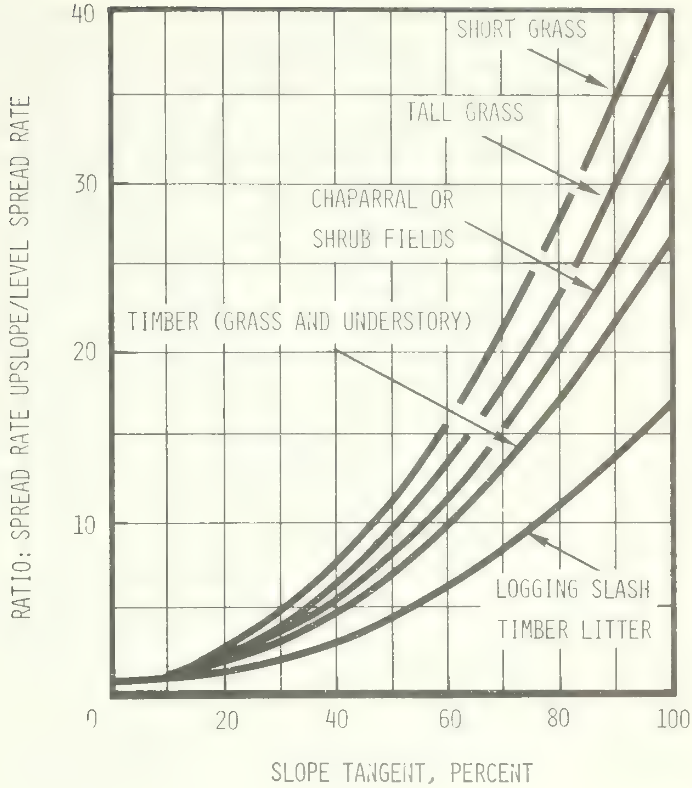


Figure 3.--Ratio of forward rate of spread downwind to the rate under calm conditions. Level terrain is assumed in both cases. Fuel models correspond to those used in the nomographs.

Figure 4.--Ratio of forward rate of spread upslope to the rate on level terrain. Zero windspeed is assumed in both cases. Fuel models correspond to those used in the nomograph.



Shape and Growth of Wind-Driven Fires

The shape of a wind-driven fire can be approximated by joining two ellipses.[5] Relationships between area, perimeter, and length of downwind travel from the point of origin are given as formulae in appendix II. The parameters that describe the elliptical shapes can be derived from these formulae also. But these quantities convey little in the way of a visual impression of the shape represented.

Figure 5 shows the shapes predicted by the equations in appendix II, for fires driven by 5-, 10-, 15-, 20-, and 30-mi/h winds. In each case, the fire is presumed to start where the two straight lines cross, and the wind blows from left to right. The typical elongated egg shape has been noted even for very large fires.[6]

The length of the perimeter of a wind-driven fire depends on how long it has been burning. By using the shapes predicted by Anderson's equations (like those shown in fig. 5), all we need to know to compute the perimeter is the length of the downwind run. On the diagrams of figure 5, this length of run is from the intersection of the two straight lines to the right-hand edge of the fire outline. Figure 6 plots the perimeter of the fire divided by length of run. To compute the perimeter length of the elliptical shapes, read the vertical axis of figure 6 for the ratio of perimeter to downwind run distance. Multiply this number by the length of the downwind run, which is simply the forward rate of spread multiplied by the time since ignition.

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[5]Reference footnote 3.

[6]Anderson, Hal E. Private communication of data on file at the Northern Forest Fire Laboratory, Missoula, Montana, December 1974.

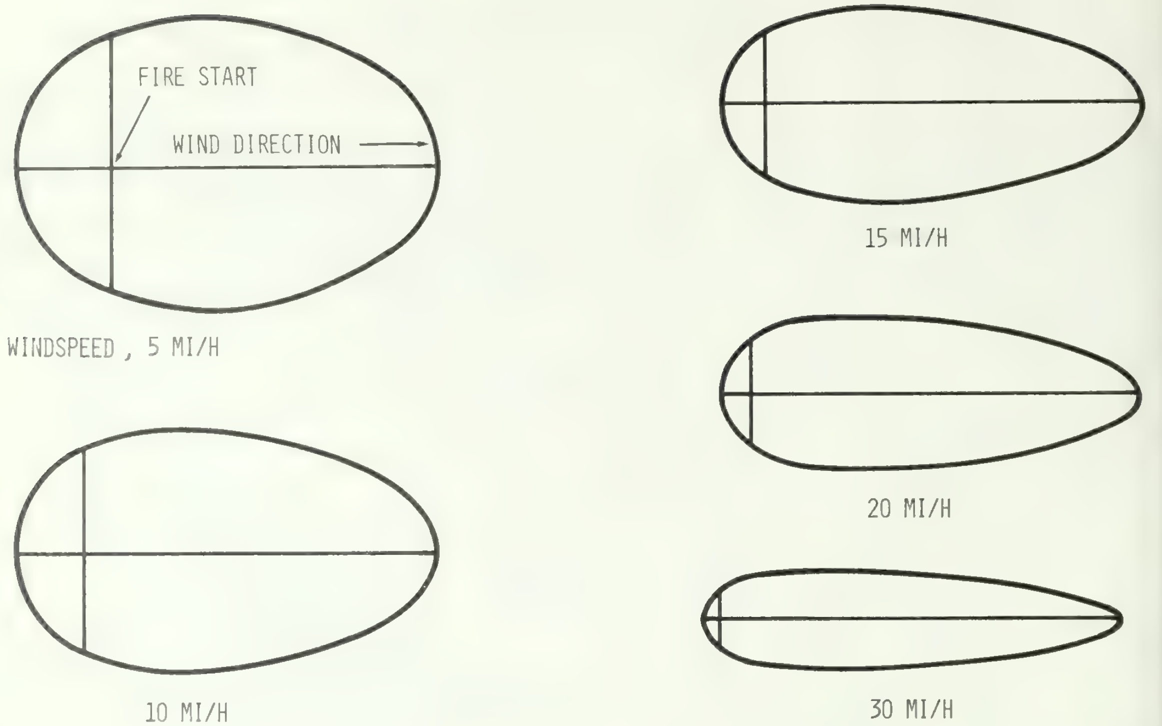


Figure 5.--Approximate fire shapes (not sizes, the scales are arbitrary) for windspeeds of 5, 10, 15, 20, and 30 mi/h.

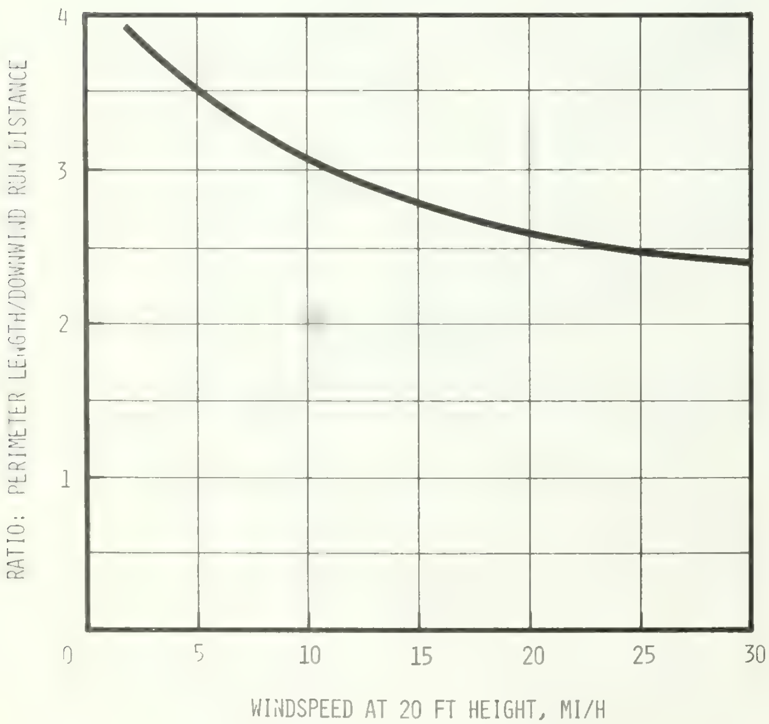


Figure 6.--Ratio of approximate fire perimeter length to the distance from point of origin to the head of the fire (based on Anderson's double-ellipse formula in appendix II).

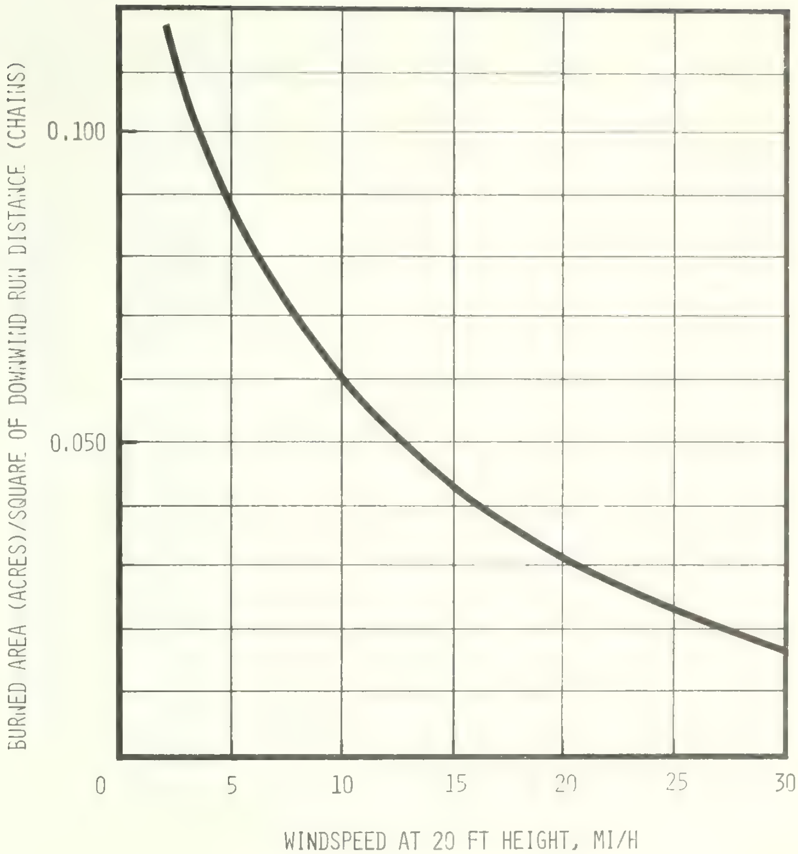


Figure 7.--Approximate area of wind-driven fires, using Anderson's double-ellipse formulae in appendix II. In this figure, the area within the approximate perimeter (acres) has been divided by the squared distance (in chains) from the point of origin to the head of the fire. Thus, this ratio decreases with windspeed while the area itself actually increases.

Note that the curve in figure 6 underestimates the fire perimeter for extremely low windspeeds. It appears from this figure that at zero windspeed (when the fire shape would be a circle) the ratio of perimeter to radius would be just greater than four, while the proper value is, of course, 6.28. The data from which the equations for figure 6 and 7 were derived were for windspeeds of about 5 mi/h and above, and the extrapolation of the curves to lower windspeeds produces some error.

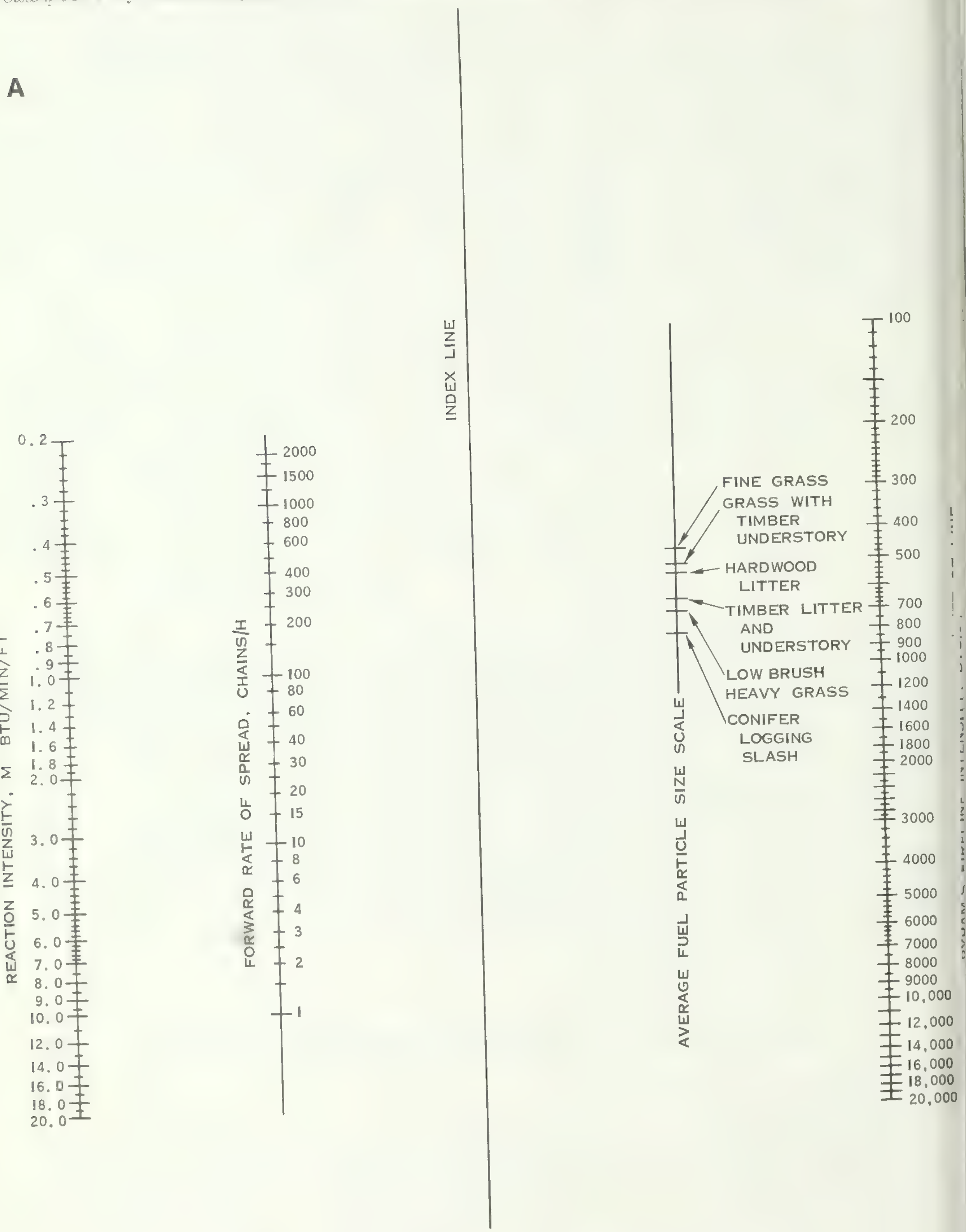
The area enclosed by this approximate perimeter affords a measure of the area of the fire. To express this area, we divide the acreage burned by the square of the downwind run length so that all fires can be represented on a single graph. In figure 7, the burned area is plotted, and divided by the square of the length of the downwind run in chains. Again, note the underestimation of fire area for very low windspeeds. The zero-wind ratio of area to square of radius would be 0.314 in the units used in figure 7.

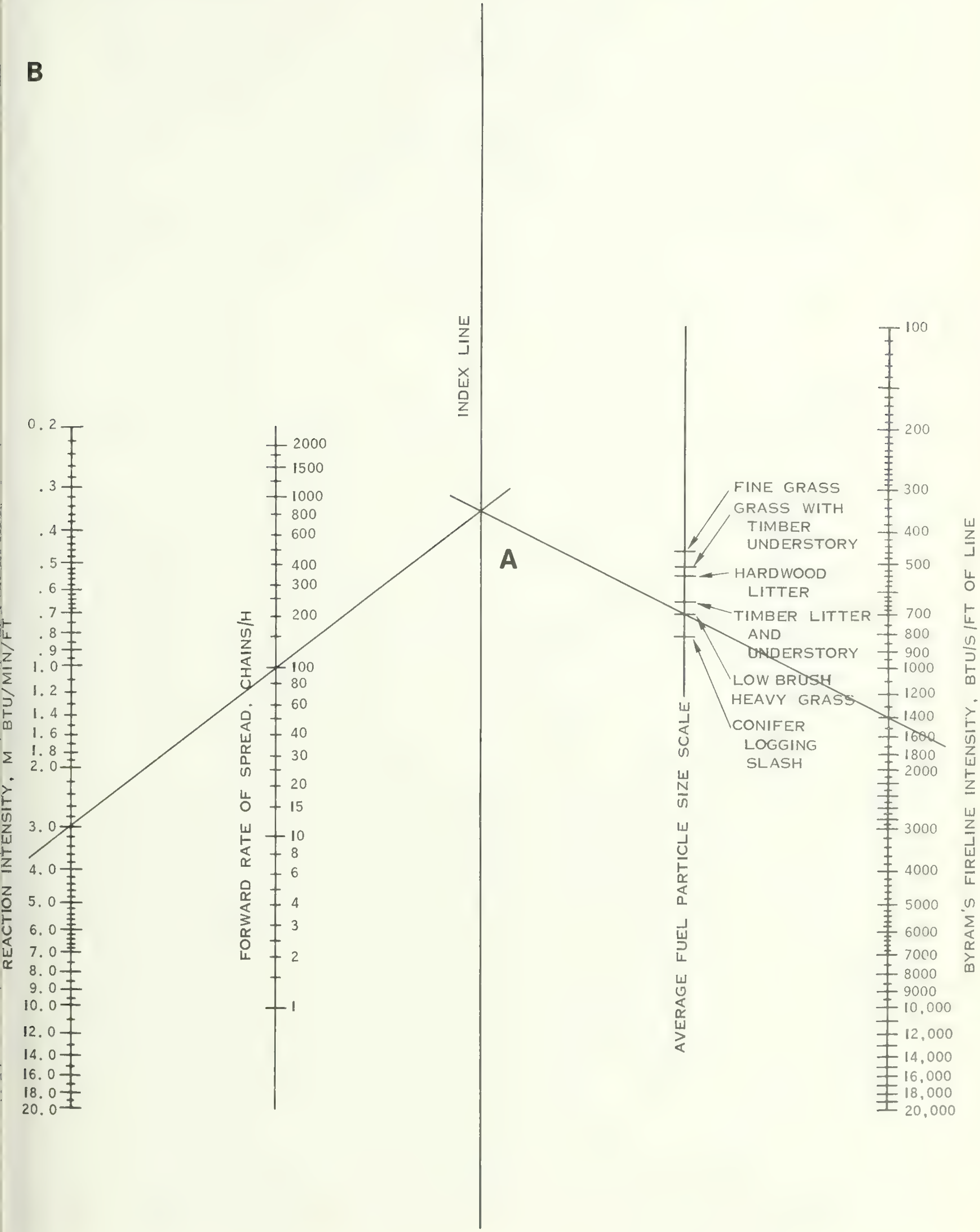
Flame Front Characteristics and Some Fire Effects

Byram's Intensity

Many researchers have used Byram's measure of intensity (appendixes I and II) to correlate observed fire behavior phenomena. This important parameter is also, by itself, a useful gage of fire intensity or resistance to control (Hodgson 1968). Figure 8 is a different type of nomograph that allows one to estimate Byram's intensity from the rate of spread and the reaction intensity (as taken from the previous nomographs), and the mean size of the fire-propagating fuel particles.

Figure 8.--A nomograph for determining Byram's intensity from the rate of spread and Rothermel's reaction intensity. B, an example of how to use A, using the results of example 1 of the nomograph explanation, 97 chains per hour and 3,000 Btu/min/sq ft.




B
A
REACTION INTENSITY, M BTU/MIN/FT
0.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.2
1.4
1.6
1.8
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
12.0
14.0
16.0
18.0
20.0
FORWARD RATE OF SPREAD, CHAINS/H
2000
1500
1000
800
600
400
300
200
100
80
60
40
30
20
15
10
8
6
4
3
2
1
INDEX LINE
AVERAGE FUEL PARTICLE SIZE SCALE
FINE GRASS
GRASS WITH TIMBER UNDERSTORY
HARDWOOD LITTER
TIMBER LITTER AND UNDERSTORY
LOW BRUSH HEAVY GRASS
CONIFER LOGGING SLASH
BYRAM'S FIRELINE INTENSITY, BTU/S/FT OF LINE
100
200
300
400
500
700
800
900
1000
1200
1400
1600
1800
2000
3000
4000
5000
6000
7000
8000
9000
10,000
12,000
14,000
16,000
18,000
20,000

To use figure 8, follow these steps:

1. Determine the reaction intensity (e.g., from the previous nomographs) and locate this value on the scale at the far left.

2. Determine (or select) the rate of spread, and locate this value on the scale next to farthest left.

3. Draw a straight line through the two points located in the previous two steps and determine the intersection of this line with the index line of figure 8 (the center line). Call this point A.

4. Determine the mean fuel particle size, from the fuel complex descriptions shown on the line next to far right.

5. Draw a straight line from point A through the fuel particle size scale at the point representing the fuel complex of interest and extend the line to intersect the far right-hand scale.

6. Where the line intersects the far right-hand scale in step 5, read off Byram's intensity.

An example is shown (fig. 8*B*), using the results of example of the nomograph explanation, 97 chains per hour and 3,000 Btu/min/ft^2.

Flame length

Figures 9 and 10 are plots of Byram's flame length formula given in appendix II. Using the value determined from the nomograph of figure 8, the average flame length

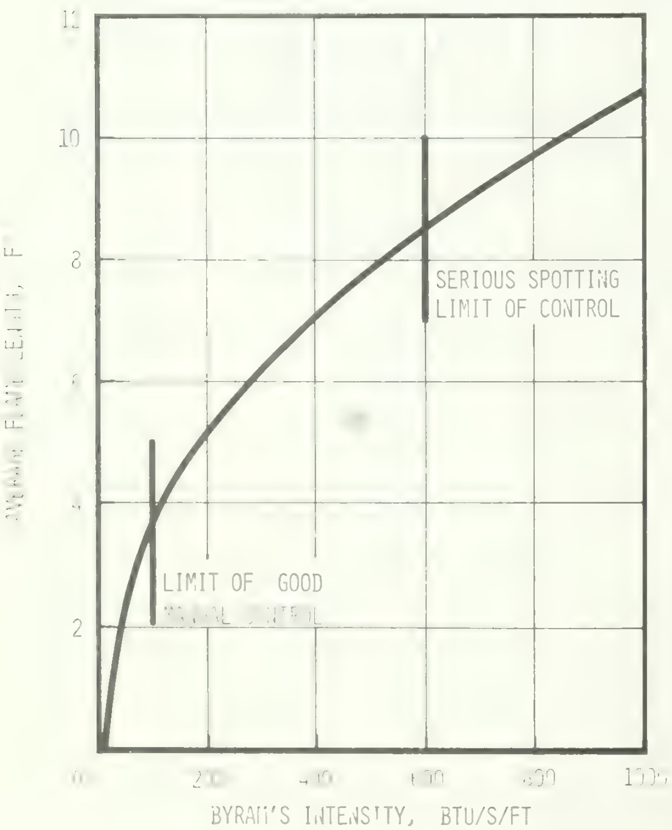
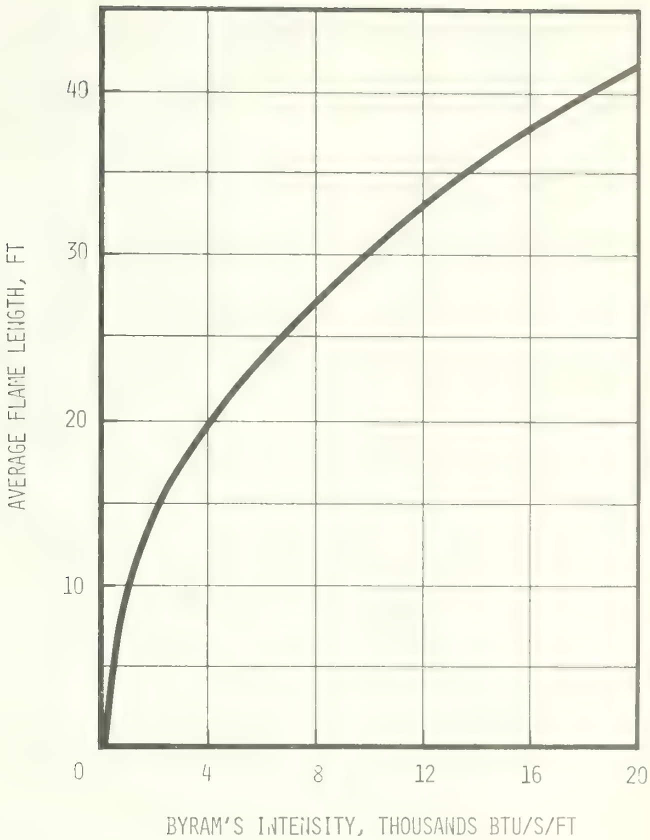


Figure 9.--Flame length versus Byram's intensity. The limits of control indicated on the figure are from Hodgson (1968).

Figure 10.--Flame length versus Byram's intensity for high-intensity fires.



can be estimated directly by reading the graphs of figure 9 or 10. On figure 9, Hodgson's (1968) limits of controllability are marked. Note the flame lengths associated with these intensities. Good manual control ceases with flame lengths greater than about 3.5 feet, and serious spotting (limit of control) is to be expected when flame lengths exceed about 8.5 feet.

Crown Scorch Height

Figures 11 and 12 plot Van Wagner's (1973) equations for the height of crown scorch versus Byram's intensity for various windspeeds on a 77° F day. (The use of the 77° F day as a standard for this calculation is discussed in the mathematical presentation of appendix II.) The sharp decrease in scorch height with windspeed for a fixed value of Byram's intensity is due to cooling of the hot plume by entrained ambient air. This is somewhat deceiving, as Byram's intensity usually increases rapidly with windspeed. (This is so because Byram's intensity is proportional to rate of spread, see appendix II and fig. 8).

Crown scorching is an important consideration in prescribed fire design, and the effect of windspeed can be an overriding factor in many cases. Due to the fact that the windspeed under a timber canopy is often nearly constant with height above the ground (Countryman 1956; Curry and Fons 1940) and significantly lower than the windspeed measured in the open, as at a nearby weather station, the value of the crown scorch height predicted by the use of the charts presented in figures 11 through 13 can be either high or low, depending on how the measured windspeed values are interpreted. The proper way to use these charts is to enter the value of Byram's intensity as determined from the previous graphs, using the 20-ft windspeed as measured in the open. But when using figures 11 through 13, use the value of windspeed *to be expected in the timber stand.* Typically, this windspeed will be half the open area windspeed or less.

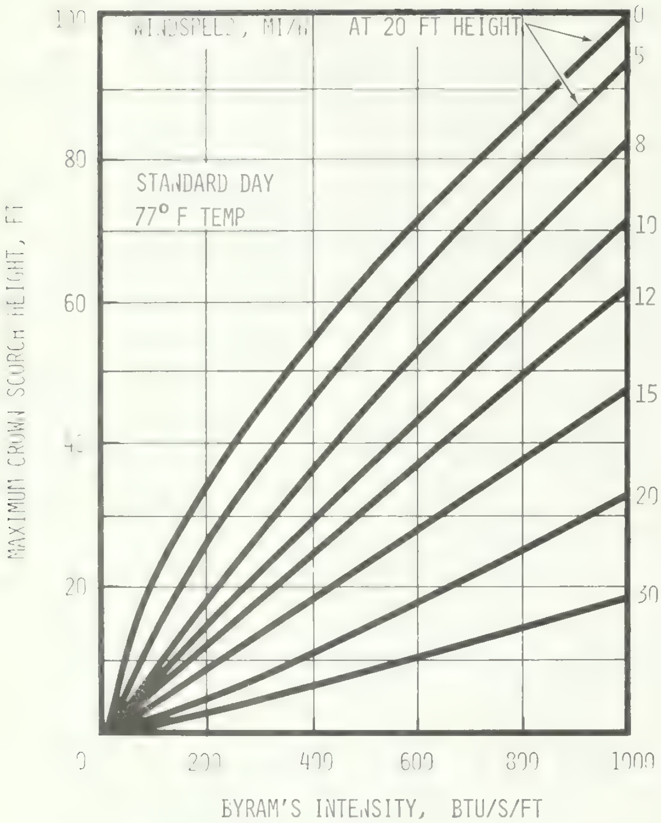


Figure 11.--Crown scorch height versus Byram's intensity (low-intensity range).

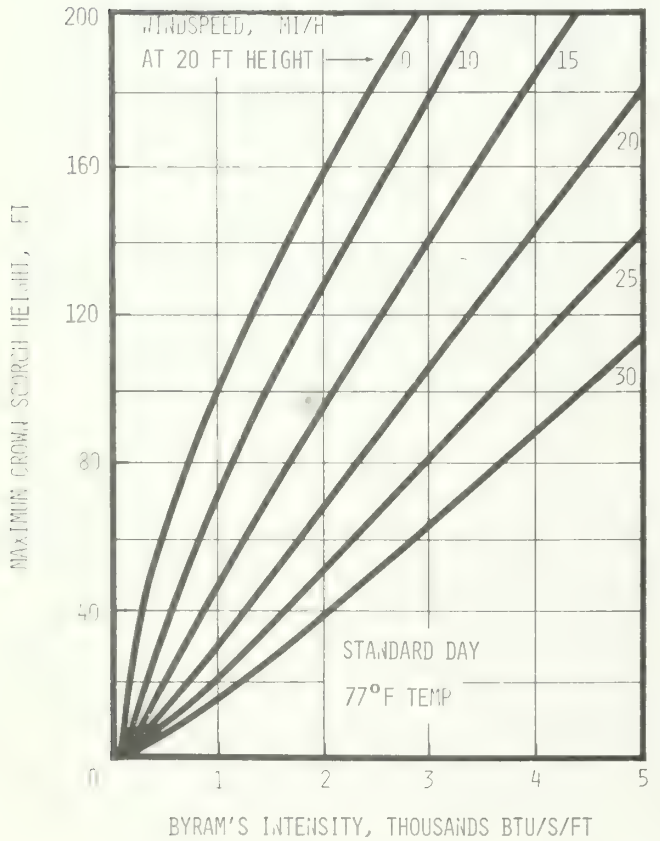
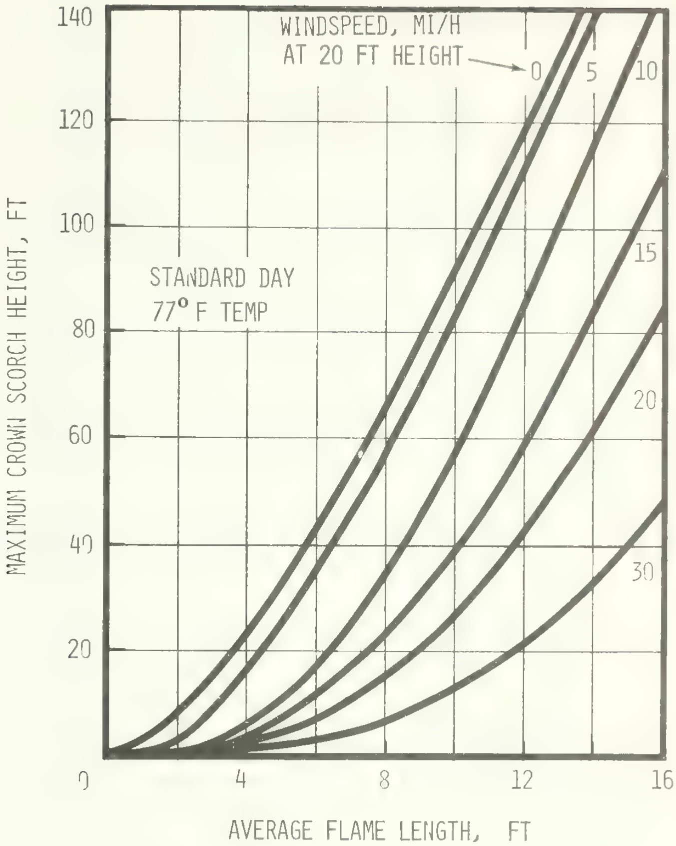


Figure 12.--Crown scorch height versus Byram's intensity (high-intensity range).

gure 13.--Maximum height of crown scorch on a 77° F day versus average flame length. Both quantities are predicted by Byram's intensity and so are directly related.



Using Byram's intensity, determined by using the nomograph of figure 8 or from eading figures 9 and 10 backwards (using the flame length determined from the rate f spread nomographs), figures 11 and 12 can be read to estimate the maximum height of ethal scorching of coniferous tree crowns over the fire, assuming that the ambient emperature is 77° F. Figure 11 is for relatively low values of Byram's intensity, uch as might be encountered in prescribed burns. Figure 12 is for much higher values f Byram's intensity, such as might be encountered in severe wildfires.

Figure 13 shows the relationship between the flame length predicted by Byram's quation and the maximum height of crown scorch on a 77° F day. Using this figure, ne can go directly from the flame lengths, as given by the nomographs, to an estimate f maximum crown scorch height.

By using figure 14, the scorch height determined from figures 11 through 13 can e adjusted for any ambient temperature. The vertical scale of figure 14 is the ratio f the scorch height on a day with ambient temperature, T, to the scorch height on a ay with ambient temperature 77° F. For the temperature of interest, on the horizontal scale, read off the ratio on the vertical scale. Multiply this value by the 77° F ay scorch height from any of figures 11, 12, or 13 to determine the scorch height on he day of interest.

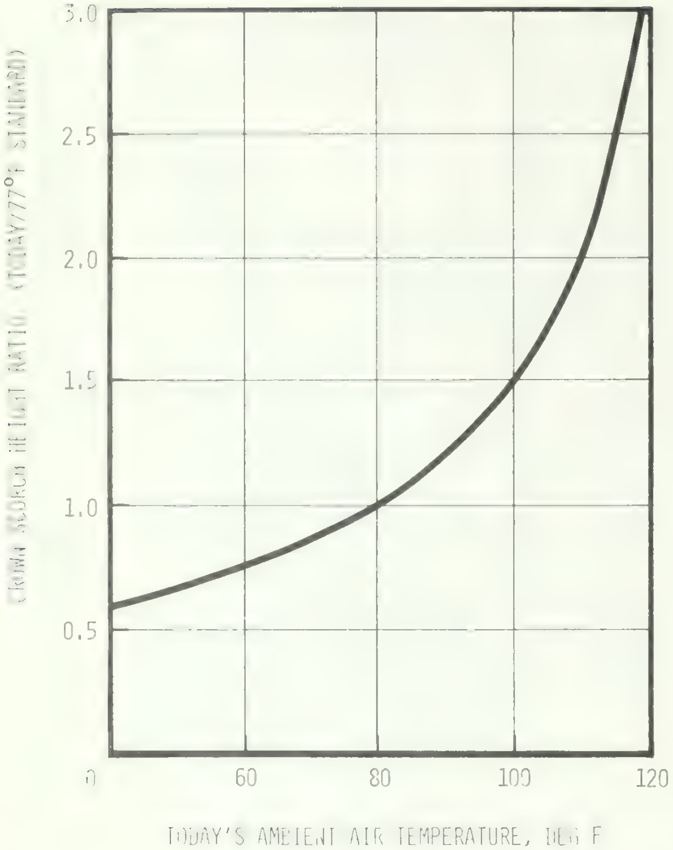


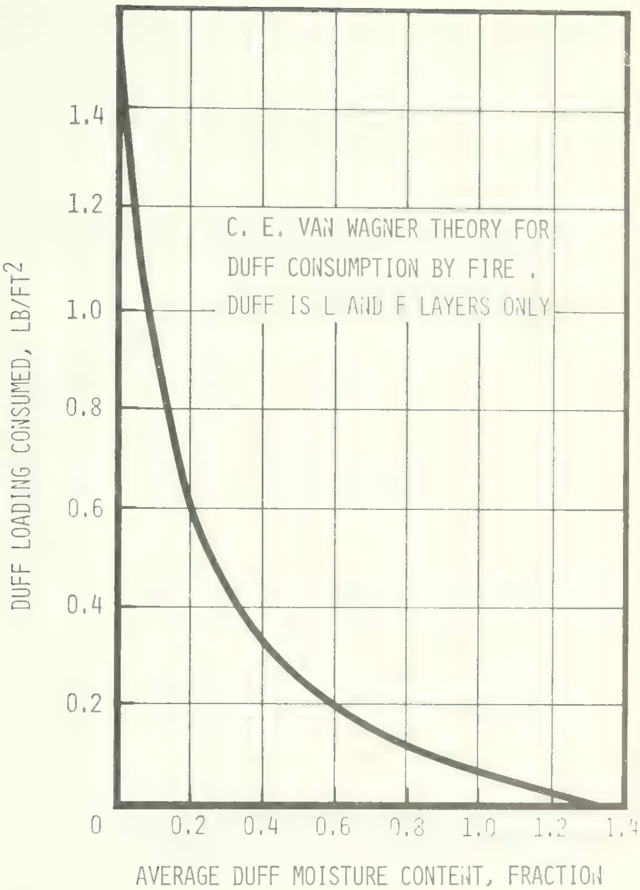
Figure 14.--Variation of scorc height with burning-day temperature. Multiply the ordinate value from this figure by the heights read from figure 11, 12, or 13 to determine maximum scorch height.

Duff Burnoff

The consumption by fire of the litter and fermentation layers of the duff mantle of the forest floor was investigated by Van Wagner (1972). A brief discussion of this work is given in appendix II. Duff consumption is achieved largely by burning after the passage of the initiating fire front, but Van Wagner found a strong correlation of the duff loading reduction to the duff moisture content, using a simple spreading-fire phenomenological model to guide the choice of functional form for the relationship.

Figure 15 is a plot of the relationship found by Van Wagner. The *reduction* in L and F layer duff loading is plotted against the average moisture content (fraction of dry weight) of these layers combined. Of course, if the total L and F layer loading is less than that predicted by figure 15, the proper interpretation is that whatever loading is present would be consumed.

igure 15.--Duff consumption by fire, as predicted by Van Wagner (1972) from average duff moisture content. Only the L and F layers of the duff mantle are considered here.



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APPENDIX I

FIRE BEHAVIOR DESCRIPTION AND QUANTIFICATION

Because there are many aspects to fire behavior, there are also many quantitative 'escriptors of fire behavior. This appendix presents some of these quantities and ppropriate units of measurement.

Measures of Growth

The shape, or map outline, of a free-burning fire is often highly irregular in etail, but the overall pattern usually resembles an ellipse. Particularly in the ase of wind-driven fires, an elongated ellipse can be drawn that corresponds roughly o the outline of the burned area.

The rate of advance of the "head" of such a fire is called the forward rate of pread. The distance around the fire, encircling the head, along both flanks, and round the backing fire at the "tail" is called the perimeter. The area enclosed by he perimeter we will call the area, or the burned area. So long as conditions remain nchanged, including the fuel being burned, the perimeter will increase linearly with ime and the area quadratically.

ates of Spread

A rate of spread, whether it be the forward rate, the rate of spread against a lank, or a backing rate, has the dimensions of velocity. The most common such elocity measurement unit in United States forestry is "chains per hour." Many other nits are used, however, particularly in research circles. Table 1 shows the numer- cal equivalence of various units of velocity measurement.

The rate of increase of the perimeter of a fire is also measured in units of elocity. Again, United States foresters rely on "chains per hour," but all other nits in table 1 could equally well be used.

Table 1.--*Equivalence of various units used to measure the rate of spread of a fire*

If units are:	Multiply by:	To obtain:
Chains per hour	1.100	Feet per minute
Chains per hour	.0183	Feet per second
Chains per hour	.0125	Miles per hour
Chains per hour	.3353	Meters per minute
Chains per hour	.5588	Centimeters per second
Chains per hour	.02012	Kilometers per hour
Feet per minute	.9091	Chains per hour
Feet per second	54.54	Chains per hour
Miles per hour	80.0	Chains per hour
Meters per minute	2.982	Chains per hour
Centimeters per second	1.79	Chains per hour
Kilometers per hour	49.7	Chains per hour

The area of a fire is most commonly measured in acres in the United States, but the metric hectare is becoming more common in the literature. Other units of area are also used. Table 2 shows the numerical equivalence of various measures of area.

Area growth rate is measured in units of area per time, such as acres/h, ft^2/min, etc. Table 3 shows the numerical equivalence of such units of measurement.

Table 2.--*Equivalence of various units used to measure the area of a fire*

If units are:	Multiply by:	To obtain:
Acres	43,560	Square feet
Acres	0.001563	Square miles
Acres	4,047	Square meters
Acres	.4047	Hectares
Acres	.004047	Square kilometers
Square feet	.0000230	Acres
Square miles	640	Acres
Square meters	.0002471	Acres
Hectares	2.471	Acres
Square kilometers	247.1	Acres

Table 3.--*Equivalence of various units used to measure the rate of area growth of a fire*

If units are:	Multiply by:	To obtain:
Acres per hour	726	Square feet per minute
Acres per hour	12.10	Square feet per second
Acres per hour	11,241	Square centimeters per second
Acres per hour	67.45	Square meters per minute
Acres per hour	.4047	Hectares per hour
Acres per hour	.0971	Square kilometers per day
Acres per hour	.0375	Square miles per day
Square feet per minute	.001377	Acres per hour
Square feet per second	.08264	Acres per hour
Square centimeters per second	.0000890	Acres per hour
Square meters per minute	.01483	Acres per hour
Hectares per hour	2.471	Acres per hour
Square kilometers per day	10.30	Acres per hour
Square miles per day	26.67	Acres per hour

Measures of Intensity

Perhaps no descriptor of wildfire behavior is as poorly defined or as poorly communicated as are measures of fire intensity. Technically, the term intensity implies some measure of a rate of energy transmission, but the term has also been applied to many aspects of wildfire behavior and effects such as peak flame temperature, convection column height, maximum soil temperature, fraction of standing timber killed, and others.

Here we shall define two explicit but virtually unobservable measures of intensity. Through various models (empirical relationships), these measures can be related to directly observable fire phenomena which can themselves serve as indirect measures of intensity.

Reaction Intensity

Reaction intensity is defined as the rate of heat release per unit area of ground beneath the fuel bed. As the front of the flaming zone moves over some point on the ground, the reaction intensity increases from zero to some maximum value and then decreases to zero (much more slowly than it increased usually), as the available fuel is consumed.

Appropriate units for this measure of intensity are (heat energy/area/time), such as Btu/ft^2/min, or Kcal/m^2/s.[7] Table 4 gives conversion factors between various units for reaction intensity.

Table 4.--*Equivalence of various units used to measure the reaction intensity of a fire*

If units are:	Multiply by:	To obtain:
Btu/square foot/minute	0.01667	Btu/square foot/second
Btu/square foot/minute	1,055	Joules/square foot/minute
Btu/square foot/minute	.004521	Calories/square centimeter/ second
Btu/square foot/minute	.04521	Kilocalories/square meter/ second
Btu/square foot/minute	1.890×10^5	Ergs/square centimeter/ second
Btu/square foot/second	60	Btu/square foot/minute
Joules/square foot/minute	.000948	Btu/square foot/minute
Calories/square centimeter/ second	221.2	Btu/square foot/minute
Kilocalories/square meter/ second	22.12	Btu/square foot/minute
Ergs/square centimeter/second	5.292×10^{-6}	Btu/square foot/minute

[7]A Btu is a British thermal unit, which is the amount of heat energy required to raise the temperature of 1 pound of water (1 pint), by 1° Fahrenheit. A Kcal is a kilogram-calorie which is the amount of heat energy required to raise the temperature of 1 kilogram of water (1 liter) by 1° Celsius (Centigrade).

Byram's Fireline Intensity

This measure of intensity is commonly used to describe wildland fire in the Un States. This intensity, as defined by Byram (1959), is the product of the availabl heat of combustion per unit area of the ground and the rate of spread of the fire. dimensions of this product are heat energy/length/time, such as Btu/ft/s or Kcal/m/ This measure of intensity can be interpreted as the heat released per unit of time each unit of length of fire edge.

Byram's intensity parameter has proved to be very useful in wildland fire beha descriptions and as a general index to what most people seem to visualize when they speak loosely of "fire intensity." For example, Australian researchers have found (Hodgson 1968) that a heat output rate per unit of fireline length should not excee 100 Btu/ft/s in order to maintain good control over prescribed burns. Hodgson also states that if Byram's intensity exceeds 600 Btu/ft/s, spotting becomes serious and the fire is, to all intents and purposes, uncontrollable. Van Wagner (1973) found the height of lethal scorching of coniferous tree crowns could be very well correla with Byram's intensity. Table 5 gives conversion factors for different units which be used to measure this intensity.

Table 5.--*Equivalence of various units used to measure Byram's fireline intensity*

If units are:	Multiply by:	To obtain:
Btu/foot/second	60	Btu/foot/minute
Btu/foot/second	1,055	Joules/foot/second
Btu/foot/second	8.268	Calories/centimeter/sec
Btu/foot/second	.8268	Kilocalories/meter/seco
Btu/foot/second	3.461×10^8	Ergs/centimeter/second
Btu/foot/minute	.01667	Btu/foot/second
Joules/foot/second	.000948	Btu/foot/second
Calories/centimeter/second	.1209	Btu/foot/second
Kilocalories/meter/second	1.209	Btu/foot/second
Ergs/centimeter/second	2.889×10^{-9}	Btu/foot/second

Flame Length

Byram also found (1959) that the average length of the flame at the edge of a free-burning fire could be predicted by the fireline intensity. Because of this relationship, flame length can be considered to be an alternative form of quantifyi Byram's intensity. But flame length itself is both a meaningful parameter[8] and a g general index to the elusive meaning of fire intensity (Van Wagner 1968a, 1973; Lawson 1972; Sneeuwjagt 1974).

Units of length measurement are easily converted if one recalls the English-to- Metric conversion factor "1 foot = 0.3048 meter" or its inverse "1 meter = 3.281 fe

[8]Flame length, for example, gives a rough minimum width of an effective fireli and a rough guide as to the likelihood of crowning of a ground fire under timber.

Site and Environmental Effects

The effects of a wildland fire on the site over which it burns and on the surround-
ng area can be many and varied. Here we mention a few effects, note the ways in which hey are quantified, and point out their relationships to descriptors of the fuel omplex, the environment, or other fire-behavior variables.

'otal Heat Release

The amount of heat released by burning a unit area of a given fuel bed is a rough ieasure of the impact that the fire would have on the site at the location of that unit rea. Because the heat produced by burning a pound of almost any forest fuel is about he same (~8,000 Btu), the total heat released by burning is nearly a direct measure f the total fuel load loss. This being so, the larger size fuel pieces can be mportant in determining total heat release, because they contribute so much to total oading per unit area whenever they occur in any significant quantity. Another im-
ortant fuel under timber or slash is the duff (or litter and duff) layer (Van Wagner 968a, 1972).

Norum (in press) has found initial fuel loadings to be important variables, s well as duff moisture content, in predicting total load loss in burns under standing imber. Stocks and Walker (1972) found slash fuel consumption (hence total heat re-
ease) to be correlated to Canadian Fire-Danger Rating indexes which are closely elated to duff moisture. Hough (1968) found fuel moisture important in predicting vailable fuel energy in backing fires, and Van Wagner (1972) found duff moisture to ive a fair prediction of (L and F) duff layer burnoff under standing timber.

Units that would be used in total heat release are (heat energy/area). Table 6 ives some conversion factors for different units for this measure of site impact.

Table 6.--*Equivalence of various units used to measure total heat release by a fire*

If units are:	Multiply by:	To obtain:
Btu/square foot	0.2713	Calories/square centimeter
Btu/square foot	2.713	Kilocalories/square meter
Btu/square foot	1,055	Joules/square foot
Btu/square foot	1.134×10^{7}	Ergs/square centimeter
Calories/square centimeter	3.687	Btu/square foot
Kilocalories/square meter	.3687	Btu/square foot
Joules/square foot	.000948	Btu/square foot
Ergs/square centimeter	8.818×10^{-8}	Btu/square foot

Duff Removal

As mentioned above, the burning of duff[9] can contribute substantially to total heat release. Also, because duff is in intimate contact with the soil, it can serve either as an insulating cover for the soil if it is not largely consumed by the fire Or it can serve as the greatest single source of heat input to the soil itself if it completely or nearly completely consumed. Because duff removal is sometimes the eff sought by prescribed burning, the secondary effect of soil heating may be very impor

Duff consumption can be measured either in terms of load reduction (loss of so many pounds per square foot, for example) or in terms of depth reduction. For many considerations, the thickness of the duff mantle is more important than its weight p unit area, but for fire behavior estimations, both parameters can be important.

The units of measurement of duff removal would be either weight/area or depth, depending upon how the investigator chose to determine or express it. Because the duff mantle is often nonuniform in the vertical direction, with the bulk density of the material changing substantially from top to bottom, the two measures cannot usua be related simply. In other words, knowledge of one such measure of duff reduction does not necessarily allow one to infer the other, without a relationship linking th two variables.[10]

Height of Crown Scorch

The maximum height of lethal scorching of conifer needles is an immediate effec of fire and an important parameter in establishing prescriptions for burning under timber. A completely scorched tree may be delayed in growth or even killed. Van Wagner has found (1973) this height to be a strong function of Byram's intensity, ambient temperature, and windspeed. Evidence has been put forth[11] that the height o lethal scorch may correlate with the height to which spruce budworm larvae are kille (or at least the number which are killed), by heat from a fire under timber.

The mechanism by which lethal needle scorching occurs is probably simply killin the live tissue, as it seems to be strongly correlated to an air temperature of abou 140° F, which proximate temperature level has been noted to be lethal to conifer foliage on exposures of 30 seconds to 1 minute (Hare 1961).

Maximum scorch height would be measured in units of length, vertically from the base of the tree to the height in the tree crown at which needles have survived the fire. This effect may not be easily detected for a week or two after a fire, but wh evident is usually noted as a distinct height in the crown. Below this height all t needles are brown and dead; above it, live and green.

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[9]Here we use the term "duff" loosely to represent the total forest floor accumu tion of detritus, from fresh litter (L layer), the decomposing layer underlying this fresh layer (the fermentation, or F layer), and the lower layer which is decaying to organic soil (the humus, or H layer). When it is important to be specific, the designators L, F, and H are used explicitly.

[10]Norum, Rodney A. 1974. Correlation data relating duff depth and weight loadi on file at Northern Forest Fire Laboratory, Missoula, Mont.

[11]Caldwell, W. D. The effect of understory burning in a larch-fir stand on larv populations of the spruce budworm, *Choristoneura occidentalis*. Intermt. For. and Ra Exp. Stn., North. For. Fire Lab., Missoula, Mont. (Unpublished manuscript, 1974.)

Particulate Production

The mechanisms of smoke (particulate) production have been studied for many years since it was learned that a smoking fire was a sign of inefficient combustion. It is known that wildland fires tend to produce more smoke when burning in mixed live and dead fuel than in dead fuel only, or when wind driven as opposed to backing or flanking (Hall 1972; USDA Forest Service, n.d.; Brown and Davis 1973; Biswell 1973).

There seem to be differing views on the relationship between fire intensity and smoke production. Most smoke is particulate matter, about half solid (containing lots of carbon) and half liquid (again, containing lots of carbon). On this basis one can say that much potential fuel energy is "lost" in smoke rather than released in the fire.[12] This means that a fire that produces a lot of smoke is not converting the stored energy of the fuel into heat energy as efficiently as possible. So this lost energy might reduce the reaction intensity of a smoky fire.

On the other hand, the only way that a lot of smoke can be produced in a short time is for a lot of fuel to be involved. So a fire that is producing lots of smoke is involving a lot of fuel and therefore might also be said to be very intense.

Paradoxically, a fire may be of fairly low intensity when measured by the rate of heat release per unit of ground area (reaction intensity), yet be of rather high intensity when measured by the rate of heat release per unit of fire perimeter (Byram's intensity), as in the case of a wind-driven grass fire. Or a lot of green fuel may be "involved" by the burning dead fuel, but not itself burned well, if at all.

Particulate production is usually quantified as an emission factor. This is a dimensionless number, the ratio of particulate-matter-weight-generated per unit-weight-of-fuel-consumed-by-fire. It is sometimes expressed as a fraction, sometimes as a percentage, and sometimes as a ratio of dissimilar weight measures, such as pounds per ton or grams per kilogram, etc. The emission factor generally increases as reaction intensity decreases, so more particulate matter is generated (per pound of fuel burned) when burning conditions are poor than when they are good. But because the rate at which fuel is consumed (on the whole) may increase rapidly as burning conditions improve, or if the fire is wind-driven, the rate of smoke generation by the fire as a whole will frequently increase.

Smoke, like many other aspects of wildfire, is probably not all bad. Current literature contains speculation about links between smoke and insect mortality and between smoke and the inhibition of fungus growth (Parmeter and Uhrenholdt (in press); Biswell 1973).

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[12]Susott, R. A. 1974. Effective heat content of forest fuels. Unpublished final report on Study Plan 2103-08 on file at Northern Forest Fire Laboratory, Missoula, Mont.

APPENDIX II

SELECTED FIRE BEHAVIOR PREDICTION MODELS

In this appendix, some fire behavior prediction models are presented and briefly discussed. The equations used to calculate the results shown in the text are given. The reader is urged to consult the cited sources for more thorough discussions of the underlying theories, data, assumptions, restrictions, etc.

Rothermel's Spread Rate Model

Rothermel (1972) published so far the most comprehensive spread rate model for wildland fuels. The basic relationship of the model is an expression of conservation energy (Thomas and Simms 1963; Frandsen 1971). The model deals solely with uniform, homogeneous beds of fuel contiguous to a smooth earth. Figure 16 shows such an idealized fuel bed and explains some of the nomenclature used in discussing the model.

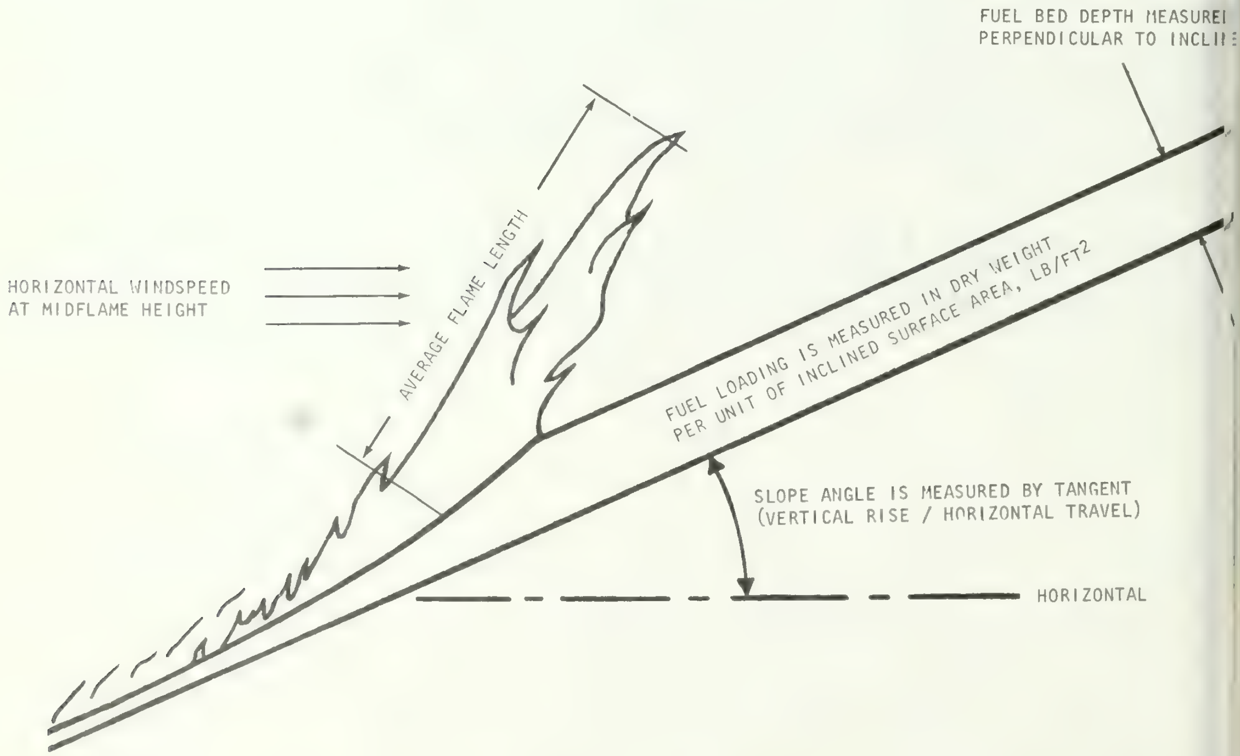

Figure 16.--Explanation of some nomenclature used in describing fire spread model and input variable definitions.

The model assumes that fire spreads by a sequence of ignitions (of the fine fuel n a mixed bed). The continued burning of a unit area of the bed proceeds largely from op to bottom, at a rate fixed mostly by the size and arrangement of the fuel particles. his burning provides the heat necessary to ignite adjacent fine fuels, and the process ycle is complete. This model is discussed here only in general terms; the equations re too complicated to be presented in detail, so the reader is urged to visit the riginal sources for details.

eaction Rate and Intensity

The rate of heat release per unit area of ground (the reaction intensity) is given y a simple formula:

$$I_R = \eta_m \eta_s \Gamma' \tilde{h} \tilde{w} \qquad (1)$$

here

$\tilde{w}$ = net loading of combustible fuel (dry weight, lb/ft^2)

$\tilde{h}$ = heat of combustion of fuel (Btu/lb, dry weight)

Γ' = maximum rate of combustion of the fuel complex, as determined by size of fuel particles and bulk density of fuel bed (min^{-1})

η_s = a factor reflecting the effect of minerals on slowing down the rate of pyrolysis of woody fuels (Philpot 1968) (dimensionless)

η_m = a factor reflecting the effect of free moisture content of the fuels on slowing down the rate of combustion (Rothermel 1972) (dimensionless)

I_R = the reaction intensity ($Btu/min/ft^2$).

For a single size class fuel bed, the indicated calculation is simple, but the omputing of weighted averages of fuel properties for beds with a mixture of fuel article sizes gets a bit complicated. The only parameters which needed determination n the laboratory in this equation were the damping coefficients η_m and η_s and the eaction velocity term, Γ'. Rothermel (1972) and Rothermel and Anderson (1966) etermined these empirical parameters.

eat Required for Ignition

A fundamental problem in predicting rate of spread of a free-burning fire is etermining the amount of heat that must be absorbed by the fuel bed to cause ignition. ot all of the mass of a fuel particle, only part of its surface, must be heated to lame-attachment temperature. In an extremely tedious but careful set of experiments, randsen (1973b) discovered that the fraction of the total loading of fuel which is eated to ignition temperature is a function of the surface area/volume ratio of the uel particles:

$$\varepsilon = \exp(-138/\sigma) \qquad (2)$$

here

ε = fraction of fuel loading heated to ignition temperature

σ = surface/volume ratio of fuel particles, ft^{-1}

With this information, one can write an expression for the total amount of heat that must be absorbed by a unit volume of the fuel bed in order to allow ignition in that unit volume:

$$Q^*_{ig} = \varepsilon\rho_b Q \tag{3}$$

where

Q = the heat required to bring a unit mass of fuel to ignition temperature (e.g., Btu/lb). This heat includes the latent heat of vaporization of all the moisture in a pound of fuel, plus the sensible heat absorbed by the fuel in raising its temperature to the point of flame attachment or "pilot ignition," about 325° C in many cases (Anderson 1970; Stockstad 1975, 1976).

ρ_b = the bulk density (lb/ft^3) of the fuel bed considered as a unit

Q^*_{ig} = the heat which must be absorbed by a unit volume of the fuel bed to bring it to the point of pilot ignition (Btu/ft^3).

Heat Flux and Rate of Spread

We have an expression for the rate of heat release per unit area of fuel bed, I_R, and an expression for the heat required to ignite a unit volume of the fuel bed, Q^*_{ig}. The missing parameter is the amount of the heat released per unit area which is absorbed by the fuel in the bed just ahead of the flame front. This quantity, represented by the symbol, ξ, (Rothermel 1972), is used to define the propagating flux, I_p, the rate of heat absorption per unit area of the fuel bed:

$$I_p = \xi I_R \tag{4}$$

Of course, ξ depends not only upon the geometrical properties of the fuel bed and particle sizes but also upon wind and slope. If the wind drives the flames into the unburned fuel bed, one would expect that a large fraction of the heat released in the burning zone would be absorbed in the unburned fuel ahead of the burning zone. Similarly, because flames tend to rise vertically, if the fuel bed is tilted, the flames will lie closer to, perhaps even touching, the top surface of the fuel bed, again increasing the value of ξ.

With these relationships, the conservation of energy equation gives an equation for the rate of spread (Thomas and Simms 1963; Frandsen 1971; Rothermel 1972):

$$I_p = RQ^*_{ig} \tag{5}$$

where R is the rate of spread in ft/min using the units mentioned here. This equation simply states that the rate at which energy is absorbed by the fuel bed per unit area (I_p) is equal to the rate at which energy per unit area is required to achieve ignition (RQ^*_{ig}). The propagating flux is the energy conserved in this relationship.

oisture of Extinction

In Rothermel's model there exists some value of fuel moisture content for which a ire would not spread. This is called the "moisture of extinction" and must be speciied by the model user. For cases in which only dead fuel components are present, the oisture of extinction has been experimentally evaluated (although not for a wide range f situations) and seldom exceeds 30 percent of dry fuel weight. Thirty percent epresents a fiber-saturation condition (Stamm 1964), but fuel moisture can exceed his value.

The moisture of extinction is probably a function of the fuel type and the geometry f the fuel bed (Byram and others 1966). For light, airy fuels (such as fine grass), moisture of extinction of about 12 percent[13] to 15 percent (Sneeuwjagt 1974) is uggested. Brown (1972) found 15 percent worked well for open beds of assembled slash uel, while for beds of pine needles, 25 to 30 percent has been observed (Rothermel nd Anderson 1966). Prescribed fires in the Southeast have been reported in pine itter, burning under conditions in which the moisture exceeded the 30 percent level[14] Blackmarr 1972).

When both live and dead fuels are present, the moisture of extinction of the live omponent is calculated from the ratio of dead-to-live fine fuel loadings and the oisture content of the fine dead fuel. The calculation is complicated, but internal o the workings of the model (Albini 1976), so need not concern the user.

When sufficient fine dead fuel exists and the dead fuel moisture content is low nough relative to its moisture of extinction, both live and dead fuel will burn, ccording to the model. In this case, the reaction intensities from the burning of the wo fuels are added together.

If the fine dead fuel loading is too light relative to that of the live fuel, or he dead fuel is too moist, the live fuel moisture of extinction may be less than the ive fuel moisture content. In this case, only the dead fuel produces a reaction ntensity, but because both dead and live fuel must be heated to the point of ignition, he fire spreads relatively slowly.

If there is no dead fuel, or if it is more moist than its moisture of extinction, othermel's model predicts no spread and no reaction intensity. Because in some cases ive fuel alone may propagate a fire (e.g., crowning in conifer stands), this restricion can be viewed as an area of incompleteness in the model.

The moisture of extinction parameter can be very important in influencing redicted wildfire behavior. The moistures of extinction used in the stylized fuel odels discussed in the text can be used as a guide to the selection of approximate alues, but direct data are to be preferred.

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[13]Countryman, C. M. Manuscript review (memorandum dated February 9, 1971, to ames K. Brown, on file at Northern Forest Fire Laboratory, Missoula, Mont.

[14]Hough, W. A. Personal communication to F. A. Albini and R. C. Rothermel at the uel Modeling Workshop held at the Southern Forest Fire Laboratory, Macon, Georgia, une 24-28, 1974.

Growth Models

Equation (5) can be used to calculate the forward rate of spread once the fuel bed is described using the additional equations in Rothermel (1972) to compute the terms in the equations given above. In this section we briefly examine the effect of wind and slope on forward rate of spread and give relationships for the shape and size of a wind-driven, free-burning fire.

Influence of Wind on Rate of Spread

The formulation of Rothermel (1972), based on experimental and theoretical work (Rothermel and Anderson 1966; Anderson and Rothermel 1965) and field data by McArthur (1969), expresses the effect of wind in the form of a factor, ϕ_w, which increases the value of the propagating flux parameter, ξ, and thus the rate of spread:

$$\xi_{\text{with wind}} = (1 + \phi_w)\xi_{\text{without wind}} \qquad (6)$$

The quantity, ϕ_w, is related to the geometrical properties of the fuel particles and fuel bed. The complete set of equations is in Rothermel (1972) but the form of the equation is:

$$\phi_w = AU^B \qquad (7)$$

where U is the windspeed (ft/min) at midflame height and A and B are "constants" depending on the fuel complex. In general, A is small for fine fuels and for tightly packed fuels and large for big and/or loosely packed fuels, while B is large for fine fuels and small for larger fuels.

The net effect of these conflicting effects is that ϕ_w is small for fine fuels at low windspeeds, but increases rapidly with increasing windspeeds. The opposite trend is true for larger fuels: ϕ_w increases rapidly for very low windspeeds but quickly "saturates" and stays nearly constant as higher windspeeds are imposed.

Examples are given in the text for several stylized wildland fuel complexes.

Beaufait (1965) obtained experimental evidence that backing fires spread at virtually the same rate as fires under still conditions. This observation has been made by others under field conditions (Van Wagner 1968a; Thomas and others 1963; Thomas 1971).

Influence of Slope on Rate of Spread

In a manner exactly analogous to the wind coefficient, a slope coefficient, ϕ_s, is used as a multiplier of the parameter, ξ, in Rothermel's model.

$$\xi_{\text{with wind and slope}} = (1 + \phi_w + \phi_s)\xi_{\text{without wind or slope}} \qquad (8)$$

The dependence of the slope coefficient on fuel bed properties is much simpler than that of the wind coefficient:

$$\phi_s = 5.275\ \beta^{-0.3}\tan^2\theta \qquad (9)$$

where

β = packing ratio = fraction of fuel bed volume occupied by fuel particles

$\tan\theta$ = slope tangent = vertical rise/horizontal travel.

ERRATA

Albini, Frank A. 1976. Estimating wildfire behavior and effects. USDA Forest Service General Technical Report INT-30, 91 pages.

Page 85, equation (10):

$$B = 0.46 \exp(-0.08756W)$$

Page 85, equation (12):

$$P \doteq \frac{\pi}{\sqrt{2}} C\{(1 + S)^{\frac{1}{2}} + (1 + Q^2S)^{\frac{1}{2}}\}$$

Overall Shape of Wind-Driven Fire

Empirical data taken by Fons were correlated and condensed to a few equations by Anderson[15] with the following general results:

1. The overall shape of the perimeter of a wind-driven wildland fire can often be approximated by two ellipses with a common semiminor axis. One ellipse will have an elongated semimajor axis in the downwind direction. The other ellipse has a shorter semimajor axis representing the progress of the backing fire.

The shape of the perimeter does not depend on the size of the fire in this formulation but only on the windspeed. Because of this fact, it is most convenient to express all distances in terms of the distance of downwind travel from the point of origin of the fire. So in the equations below, all distances are expressed relative to this length, which is simply the product of the forward rate of spread and the time since ignition if conditions remain constant.

Let W be the windspeed at 20-ft height, mi/h, and assume that this is twice the midflame height windspeed used by Anderson[15] in the correlation equations. Let B be the distance traveled upwind (backing) from the point of origin, relative to the downwind distance. Then:

([illegible]) - See errata sheet

$$B = 0.46 \exp(-0.04325W) \tag{10}$$

Let C be the maximum distance traveled crosswind (perpendicular to the wind direction) relative to the distance from the point of origin to the head of the fire. Then, from Anderson's formulae:

$$C = 0.748 \exp(-0.03608W) \{(1 + B)/(1 + Q)\}^{1/2} \tag{11}$$

where

$Q = 1.16 \exp(0.04325W)$.

2. The perimeter of the elliptical shape which roughly outlines the burned area, expressed in ratio to the distance from the point of origin to the head of the fire is given by P,

where, approximately

$$P \doteq \{\frac{\pi}{\sqrt{2}} (C^2 + (1 + B)^2/(1 + Q)^2)^{1/2} + (C^2 + Q^2(1 + B)^2/(1 + Q)^2)^{1/2}\},$$

or

$$P \doteq \frac{\pi}{\sqrt{2}} C \{(1 + S)^{1/2} + \cancel{(1 + QS)^{1/2}}\} \tag{12}$$

$(1 + Q^2S)^{1/2}$ See errata sheet

where

$S = 3.19\, C^2 \exp(0.14432W)$.

3. The area enclosed by the smooth, double-ellipse shape, divided by the square of the distance from the point of origin to the head of the fire, is given by A,

where

$$A = \pi C (1 + B)/2. \tag{13}$$

[15]Reference footnote 3.

Examples of wind-driven fire shapes, as predicted by these formulae, as well as graphs of the perimeter length (equation 12) and burned area (equation 13) are given in the text.

The simple formulae given by Van Wagner (1969) require three values of the rate of spread (heading, flanking, and backing) but don't use the windspeed explicitly. The shapes and rates of increase predicted by his method should be very similar to those given by Anderson's formulae.

Flame Front Characteristics

As mentioned earlier, several fire behavior descriptors have been related to Byram's fireline intensity. Rothermel's model deals with reaction intensity, but a simple relationship found by Anderson (1969) allows one to transcribe the reaction intensity to Byram's intensity.

Residence Time and Flame Depth

The depth, or front-to-back distance, of the actively flaming zone of a free-spreading fire can be determined from the rate of spread and the particle-residence time. Anderson (1969) found that fuel particles with diameter d (in inches) actively flamed for a time, t, where

$$t(\text{minutes}) = 8d\ (\text{inches}) \tag{14}$$

Clearly, the product of the rate of spread and the flaming time should give the depth, D, of the flaming zone:

$$D = Rt. \tag{15}$$

Byram's Intensity

Byram's intensity, I, is the rate of heat release per unit of fire edge. The reaction intensity, I_R, provided by Rothermel's spread model is the rate of energy release per unit area in the actively flaming zone. So, in terms of the depth of the flaming zone, D, described above:

$$I = I_R D/60 \tag{16}$$

The factor 60 is to convert from Btu/ft/min to Btu/ft/s.

Flame Length

Byram's formula (1959) makes it easy to calculate the average flame length from I, if I is in Btu/ft/s:

$$L = 0.45(I)^{0.46} \tag{17}$$

where

L = flame length, ft

I = Byram's intensity, Btu/ft/s.

Thomas (1963, 1970) found a very similar formula, but he used the rate of fuel consumption per unit length of fire edge rather than the intensity, I, to express his results. If we assume that the heat of combustion of the fuel particles is 8,000 Btu/lb, we can rewrite Thomas' equation in terms of I, with the result:

$$L = 0.20\ I^{2/3}$$

There are theoretical reasons to prefer the 2/3 exponent of Thomas' equation, n some experiments (Thomas 1963, 1970; Thomas and others 1963; Putnam 1965; Anderson n others 1966) tend to confirm this power law, but Byram's equation seems to give de realistic results over a wide range of intensities (Brown and Davis 1973) and is sd here to predict flame length.

rum Scorch Height

Van Wagner's formula (1973) for maximum height of lethal scorch can be written n English units as:

$$H_s = (63/(140 - T)) \left(I^{7/6}/(I + W^3)^{1/2}\right) \qquad (18)$$

hre

W = windspeed at 20 ft height, mi/h

I = Byram's intensity, Btu/s/ft

T = ambient air temperature, °F

H_s = maximum height of lethal scorch, ft.

Because there are three variables in equation (18), it is possible to deal with w equations which are each simpler. Note, for example, that if the temperature (T) ee 77° F, we would have a simpler formula:

$$(H_s)_{77^\circ\ F} = I^{7/6}/(I + W^3)^{1/2} \qquad (19)$$

cwe can pick a standard day as being a 77° F day, and refer all other crown scorch eghts to this standard. If the intensity (I) and the windspeed (W) were the same c two different days, but the temperatures were different, the scorch heights cld be in the ratio:

$$\frac{(H_s)_{\text{Temperature T}}}{(H_s)_{77}} = \frac{63}{140-T} \qquad (20)$$

Duff Burnoff

Van Wagner (1972) conducted experimental burns under standing pines in eastern aada to determine the amount of duff burned off under various conditions. He cnd that the weight loading (dry weight, lb/ft^2) of combined L and F layers con- ued by fire was strongly related to the average moisture content of these duff aers. The equation derived by Van Wagner included theoretical justification based r the variation of flame emissivity with water content. In units used herein, this cation is:

$$W = 0.1926\ (1.418 - M)/(0.1774 + M) \qquad (21)$$

re

W = duff loading burned off, lb/ft^2

M = duff (L + F) average moisture content, fraction of dry weight. This equation sgraphed in the text.

APPENDIX III

BASIS FOR CONSTRUCTION OF THE NOMOGRAPHS

Mathematical Basis

The nomographs represent a graphical means of performing the computations specified by Rothermel (1972) for determining reaction intensity and rate of spread, with minor modifications. The computations were performed July 25, 1974, on the CDC 7600 computer at the Lawrence Berkeley Laboratories Computer Center (BKY) located on the campus of the University of California at Berkeley. The program used was the FIREMODS library (Albini 1976) of computer subroutines maintained on permanent storage at BKY by the Northern Forest Fire Laboratory.

The modifications of the equations (Rothermel 1972) which are significant in the computations resulting in these nomographs are outlined briefly below. Other revisions have been made, but are inconsequential for these computations (Albini 1976).

1. The dry-weight loading of any particular fuel element, W_o, includes the noncombustible mineral fraction, S_T. The loading of combustible fuel is $W_o(1 - S_T)$, not $W_o/(1 + S_T)$, as in Rothermel (1972).

2. The equation for reaction velocity, Γ', includes an exponent A, calculated from equation (39) (Rothermel 1972):

$$A = (4.77\ \sigma^{0.1} - 7.27)^{-1}.$$

In the computer-based model, this equation is replaced by

$$A = 133\ \sigma^{-0.7913}$$

to prevent divergence of results as σ approaches $(7.27/4.77)^{10}$. The differences are small but noticeable between the two methods of computation.

3. The calculation of the moisture of extinction of the live fuel loading (Fosberg and Schroeder 1971) is described by Rothermel's (1972) equation (88), which can be written as

$$(M_x)_{living} = 2.9\ W(1 - (M_f)_{dead}/0.3) - 0.226 \quad \text{(minimum value 0.3)}$$

where

$(M_x)_{living}$ = Moisture of extinction of living fuel

W = Ratio of "fine" fuel loadings, dead/living

$(M_f)_{dead}$ = Moisture content of "fine" dead fuel.

In the computer-based model, this equation is replaced by

$$(M_x)_{living} = 2.9\ W'(1 - (M'_f)_{dead}/(M_x)_{dead}) - 0.226$$

$$\text{(minimum value } (M_x)_{dead})$$

where

$$W' = (\Sigma_{dead} W_{o,j} \exp(-138/\sigma_j))/(\Sigma_{live} W_{o,j} \exp(-500/\sigma_j))$$

$$(M'_f)_{dead} = (\Sigma_{dead} W_{o,j} M_{f,j} \exp(-138/\sigma_j))/(\Sigma_{dead} W_{o,j} \exp(-138/\sigma_j))$$

and

$W_{o,j}$ = dry weight loading of size class j

σ_j = surface/volume ratio of size class j

$M_{f,j}$ = moisture content of size class j

The exponential weighting factors, developed by W. H. Frandsen[16] make explicit the calculation of "fine" fuel properties for an arbitrary fuel description, and replacement of 0.3 by $(M_x)_{dead}$ stabilizes model behavior over a wide range of moisture-of-extinction of the dead fuel.

4. In Rothermel's equation (58), the reaction intensity of the dead and living fuel categories were combined by forming a weighted average where the weighting factor was the fraction of fuel surface area per unit of ground area contributed by each category. In the computer-based model the intensities are simply added together. This change is due to a revision in the method of categorizing fuel components; only two categories (live and dead) are now employed, while at the time Rothermel published his findings (1972), it was felt that categorization by species might be more useful.

Nomograph Organization

The nomographs are organized into three functional quadrants: the two right-hand quadrants and the upper left-hand quadrant; an auxiliary working chart is inset in the lower left-hand quadrant above the lone index line.

[16]Unpublished results, discussed in Albini (1976).

The upper right-hand quadrant represents a graph of reaction intensity (right horizontal axis) versus dead fuel moisture (right vertical axis). For the fuel models presented here, the dead fuel moisture can be taken to be the 1-hour fuel moisture in all cases except models 11-13 (conifer slash), models 6 (dormant brush or hardwood slash), and 7 (southern rough). For these models, one can use an average moisture computed from Rothermel's (1972) area-weighted formula:

$$(M_{fuel})_{dead} = 0.76(M_{1-h}) + 0.18(M_{10-h}) + 0.06(M_{100-h}) \text{ Models 11-13}$$

or

$$(M_{fuel})_{dead} = 0.89(M_{1-h}) + 0.09(M_{10-h}) + 0.02(M_{100-h}) \text{ Models 6, 7}$$

For those models that include live fuel, only the foliage moisture is used, and the foliage component is included in the fuel loadings.

The lower right-hand quadrant represents the combined effect of wind and slope on amplifying the propagating flux, which is proportional to the reaction intensity. The wind coefficient, ϕ_w, and the slope coefficient, ϕ_s, are combined using the auxiliary working chart in the lower left-hand quadrant to produce an effective windspeed which when used in the formula for the wind coefficient, produces an amplification factor equal to the sum of the two coefficients:

$$\phi_w \text{ (effective windspeed)} = \phi_w \text{ (measured windspeed)} + \phi_s \text{ (slope)}$$

The lower right-hand quadrant is thus a plot of straight lines of slope $(1 + \phi_w)$ relating amplified propagating flux to reaction intensity. In all cases it is assumed that the windspeed at midflame height is half the measured windspeed at 20 feet above ground.

The lower left-hand quadrant is nonfunctional, serving only to translate the propagating flux to the horizontal axis of the upper left-hand quadrant.

The upper left-hand quadrant represents a plot of the rate of spread (center vertical axis) versus the propagating flux (left horizontal axis, running right to left). The relationship plotted is (Rothermel 1972; Frandsen 1971):

$$R = I_p/Q^*_{ig}$$

where R is spread rate, I_p is propagating flux, and Q^*_{ig} is the bulk heat of preigniti[on]. For models that have dead fuel only, Q^*_{ig} is simply a function of the dead fine fuel (1-h) moisture content.

For models that contain both live and dead fuel components, Q^*_{ig} is the function [of] both the dead fine fuel moisture and the live foliage moisture, so the slope of the appropriate line $(1/Q^*_{ig})$ relating the two variables must be constructed for each combi[-]nation of interest. Because the right-hand vertical axis is essentially the 1-hour timelag dead fuel moisture for these models, a curve for constant live foliage moistu[re] can be constructed in the upper left-hand quadrant which represents the locus of end points of straight lines of slope $(1/Q^*_{ig})$ drawn from the origin to the vertical locat[ion] of the dead fuel moisture. This allows the simple construction of the appropriate straight line of slope $1/Q^*_{ig}$ for the combination of live and dead fuel moistures.

The flame length curves in the upper right-hand quadrant are based on the simple proximation for depth of flaming zone, D:

$$D = (\text{rate of spread}) \times (\text{flaming zone residence time}) = Rt_R$$

hre

$t_R = 384/\tilde{\sigma}$ = particle residence time in flaming zone, minutes.

h correlation of particle size, as represented by $\tilde{\sigma}$, a composite surface/volume aio for the fuel bed, with flaming zone residence time is according to Anderson (1969).

The product of flaming zone depth, D, and reaction intensity, I_R, represents an proximate value of Byram's fireline intensity, I.

$$I = I_R D$$

hs intensity can be used to estimate flame length, L, from the correlation equation Bram 1959):

$$L = 0.45\ I^{0.46}\ (L \text{ in ft, } I \text{ in Btu/ft/s})$$

Combining these equations yields a family of hyperbolae of the form

$$RI_R = K(L)^{1/0.46}$$

hre K is a proportionality constant incorporating the numerical factors and rationalzng the systems of units employed in the above equations.

The Stylized Fuel Models

The descriptions of the fuel models used in constructing the nomographs are given ntable 7. The other variables needed to complete the descriptions for use in the ie spread model are held constant for the entire set. These variables are:

Ovendry fuel density	:	32 lb/ft^3
Heat of combustion (low heat value)	:	8,000 Btu/lb
Total mineral content	:	5.55 percent
Silica-free ash content (effective mineral content)	:	1.00 percent

These fuel models are very similar to the nine stylized fuel models (A - I) mloyed in the National Fire-Danger Rating System (Deeming and others 1974), but hre are some important differences. The accuracy with which any particular situation nthe field is reproduced by one of these stylized models is highly variable. The sr is urged to note discrepancies between fuel situations in the field and the tlized models used here in order to better interpret results obtained by using the opgraphs given in the text.

Table [illegible].--Description of fuel models used in constructing the nomographs

Model	Typical fuel complexes	Surface-to-volume ratio (ft^{-1})/Loading (lb/ft^2): Dead fuel 1-h	Dead fuel 10-h	Dead fuel 100-h	Live fuel (Foliage)	Depth (ft)	Moisture of extinction, dead fuel (percent)
	GRASS AND GRASS-DOMINATED						
1	Short grass (1 ft)	3500/.034	--	--	--	1.0	12
2	Timber (grass and understory)	3000/.092	109/.046	30/.023	1500/.023	1.0	15
3	Tall grass (2.5 ft)	1500/.138	--	--	--	2.5	25
	CHAPARRAL AND SHRUBFIELDS						
4	Chaparral (6 ft)	2000/.230	109/.184	30/.092	1500/.230	6.0	20
5	Brush (2 ft)	2000/.046	109/.023	--	1500/.092	2.0	20
6	Dormant brush, hardwood slash	1750/.069	109/.115	30/.092	--	2.5	25
7	Southern rough	1750/.052	109/.086	30/.069	1550/.017	2.5	40
	TIMBER LITTER						
8	Closed timber litter	2000/.069	109/.046	30/.115	--	0.2	30
9	Hardwood litter	2500/.134	109/.019	30/.007	--	.2	25
10	Timber (litter and understory)	2000/.138	109/.092	30/.230	1500/.092	1.0	25
	LOGGING SLASH						
11	Light logging slash	1500/.069	109/.207	30/.253	--	1.0	15
12	Medium logging slash	1500/.184	109/.644	30/.759	--	2.3	20
13	Heavy logging slash	1500/.322	109/1.058	30/1.288	--	3.0	25

☆U.S.GOVERNMENT PRINTING OFFICE:1976-O-677-328/6

Albini, Frank A.
1976. Estimating wildfire behavior and effects. USDA For. Serv. Gen. Tech. Rep. INT-30, 92 p. 74 ref. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

This paper presents a brief survey of the research literature on wildfire behavior and effects and assembles formulae and graphical computation aids based on selected theoretical and empirical models. The uses of mathematical fire behavior models are discussed, and the general capabilities and limitations of currently available models are outlined.

OXFORD: 431.6: 432: 436.
KEYWORDS: fire control, fire behavior model, fire management, computer program.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
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AMERICAN REVOLUTION BICENTENNIAL

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U.S. FORESTRY CENTENNIAL

FOREST FIRE RETARDANT RESEARCH

A STATUS REPORT

Charles W. George
Aylmer D. Blakely
Gregg M. Johnson

USDA Forest Service General Technical Report INT - 31
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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ABSTRACT

Forest fire retardant research was divided into five different study areas: (1) retardant effectiveness; (2) retardant physical properties; (3) retardant delivery systems; (4) retardant-caused corrosion; and (5) retardant environmental impact. Past research is reviewed for each study area; current and future research needs are described.

USDA Forest Service
General Technical Report INT-31
1976

FOREST FIRE RETARDANT RESEARCH
A STATUS REPORT

Charles W. George
Aylmer D. Blakely
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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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INTRODUCTION

One method of attacking wildland fires involves aerial or ground delivery of water r fire retardant chemicals directly on or ahead of the fire in an attempt to slow or ontain it. Fire control agencies in the United States use approximately 20 million allons of retardant annually in the suppression of wildfires. The cost of the fire etardant chemical exceeds $5 million. Costs associated with the delivery and applica-ion of this chemical run the total to approximately $25 million annually. Because uch large quantities of chemical are being used and the costs involved in delivery and pplication are high, potential savings could be realized by increasing the effective-ess of the chemical, and improving methods of delivery, application, strategy and actics, and through the use of operational guidelines.

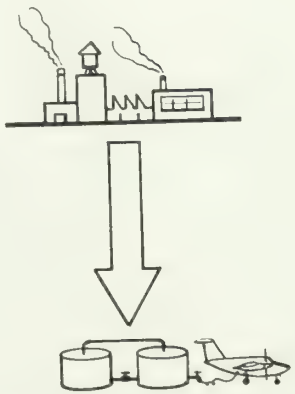
In this report, the terms "delivery" and "application" refer to the interactions tween the retardant and the fuel complex on which it is used. The tactics and correct lacement of retardant by aircraft or by a nozzleman are presently considered to be lated primarily to experience and training. The actual tactics are only superficially iscussed in this report, but many of the study results can be used in determining the ost effective retardant use.

Data from past research (reviewed in each Research Summary section of this paper) ve helped to develop standards for retardant performance in laboratory comparison sts and related performance in operational use. Developments in aerial delivery stems have been limited to speculative changes rather than those based on quantified iteria and objective testing. This report summarizes studies that have been conducted determine the retardant chemicals and delivery systems that would best aid in control-ng wildfires. Current and future studies (reported in the Current Research sections) ll determine the chemical-physical retardant properties that will optimize retardant livery and distribution within the fuel complex as a function of the fuel, the fire tuation, environmental conditions, and other influencing factors. Figure 1 shows the rameters that must be quantified and considered when formulating retardant use to ecific needs. Some knowledge of these parameters is being used now, but as more data e available, understood, and correctly applied, fire managers will be able to correctly oose both the fire retardant formulations and the dispensing mechanism to provide the fest and most effective fire attack system.

Current research at the Northern Forest Fire Laboratory has been organized into ve different study areas: retardant effectiveness, retardant physical properties, tardant delivery systems, retardant-caused corrosion, and environmental impact. Nu-rous interrelated studies are being conducted within each subject area through in-house ojects, by cooperative efforts with other Federal and State agencies, and by contrac-rs. These studies will provide much of the data needed, as shown in figure 1, to timately tailor retardant use to specific needs. Continued testing of products will d in upholding quality standards and screening new materials as they are submitted r approval.

PRODUCT FORMULATION AND EVALUATION

- TYPE OF CHEMICAL
- PHYSICAL PROPERTIES
- TOXICITY
- RELIABILITY
- RELATIVE EFFECTIVENESS



BASE REQUIREMENTS

- RHEOLOGY
- STABILITY
- SAFETY
- MIXING
- PUMPING
- CORROSION

RETARDANT CLOUD CHARACTERISTICS

- DISPERSION
- BREAKUP
- DROPLET SIZE
- RHEOLOGY

ENVIRONMENTAL IMPACT

- PLANTS
- SOIL
- MICRO-ORGANISMS
- WATER
- FISH
- PEOPLE & OTHER ANIMALS

DELIVERY CHARACTERISTICS

- TYPE OF PLATFORM
- TANK & GATES
- RETARDANT FLOW RATE
- FLUID GEOMETRY
- CAPACITY
- CORROSION
- SAFETY
- ACCURACY

FIRE SITUATION EFFECTIVENESS

- DISTRIBUTION WITHIN VERTICAL FUEL COMPLEX
- STRATEGY & TACTICS
- FIRE CHARACTERISTICS
- PATTERN QUANTITY ON CRITICAL FUEL
- SOLUTION EFFECTIVENESS
- RHEOLOGY
- SAFETY

RETARDANT EFFECTIVENESS

Research Summary

Barrett (1931) conducted one of the first documented studies to determine the asibility of using water-containing chemicals to extinguish or retard wildland fires. al interest did not develop, however, until Truax (1939), utilizing his experience th fire retardant treatments for reducing the flammability of lumber, conducted boratory tests with water solutions of chemicals to determine their fire extinguishing ility on flaming and glowing combustion. Finding that some chemical solutions were r superior to water for extinguishment, Truax conducted field evaluations of the st promising chemicals on various types and arrangements of natural fuels. Results the tests indicated that the retardant effectiveness of the chemical depended upon e type of chemical, its concentration, the rate of application, the fuel type and rangement, weather conditions, and fire characteristics. Of the various chemicals sted, ammonium phosphate was found to be the most effective.

Tyner (1941) verified the results of Truax and expanded studies to include investigations of synergistic effects of various combinations of chemicals. For the chemicals d mixtures evaluated, significant synergistic effects were not identified.

Other additives, such as wetting agents, to increase the effectiveness of water have en investigated in numerous studies (Fons 1950; Fry 1951; Miller and Wilson 1957; illips and Miller 1959; and Davis and others 1961). Although many of these additives creased the water retention or penetration, neither treatment improved the extinguishig or retarding ability of water to the extent attained by the addition of ammonium osphate compounds tested earlier.

During Operation Firestop (1955a), tests were conducted that considered aspects of emical effects on the ignitibility of fuels and on the intensity of fires in partially eated fuels. A misunderstanding of retardant action on ignitibility caused investigars to incorrectly conclude that sodium calcium borate was the best firefighting emical. In these tests, ammonium phosphate compounds actually caused cellulosic fuels ignite at lower temperatures than water-treated or untreated fuels. The investigators d not, however, consider that ignition sooner and at lower temperatures did not necesrily mean that combustion would be sustained when external heat was reduced. (This ct was shown in later studies of the effect of ammonium sulfate and phosphate on e pyrolysis and combustion of cellulose by George and Susott [1971].) The Operation restop retardant studies led to operational use of chemicals that owed their effectiveness primarily to physical properties providing greater or longer moisture retention.

New interest in ground application of chemicals on cellulosic fuels stimulated the racuse University Research Institute to conduct comprehensive studies on the effects water additives on the extinguishing efficiency of water (Aidun 1960). The studies monstrated that viscous water was about four times more efficient than plain water in tinguishing certain types of laboratory fires. Fires extinguished with viscous water re also less apt to rekindle than those extinguished with plain water. These results re operationally verified during field tests and operational use of viscous water d algin gel (Davis and others 1962).

During laboratory tests to evaluate the effectiveness of forest fire retardants on controlled open burning fires, it was determined that thickened ammonium phosphate, ammonium sulfate, and sodium calcium borate were most effective in reducing the rate of fire spread, radiant energy flux (intensity), and convection column temperature (Hardy and others 1962). The effectiveness of each chemical was a function of the type of chemical and fuel dryness, fire intensity, and environmental conditions. While carefully controlling the dryness and environmental conditions, Rothermel and Hardy (1965) found that all the tested viscous retardants had similar drying rates. Those retardants containing ammonium sulfate or ammonium phosphate chemicals, however, were effective even after their moisture had evaporated.

In a study to relate retardant effectiveness with vertical distribution, Swanson and Helvig (1973, 1974), under contract to the Forest Service,[1] developed a vertical fuel coverage model as a method of providing estimates of the vertical fuel distribution on required retardant quantities. The model views the vertical fuel structure as a series of geometrical segments each described in terms of measured fuel parameters, i.e., geometry, surface area, and volume. The model allows retardant to enter vertically, pass through each fuel segment, and be captured or retained until the surface is saturated. The model was developed on the basis of forest hydrological and retardant dispersion studies (Anderson 1974, Grah and Wilson 1944, and Leonard 1967) and can be calibrated for materials with specified rheological properties. Thus the model can be used to study the effect of various retardant characteristics including film thickness, salt content, fuel type, and the amount of retardant applied to the top of the fuel structure.

George and Blakely (1970) pointed out that in test fires to evaluate the effects of retardant chemicals applied to mat-type fuel beds, the chemicals may have similar effects on rate of spread but different effects on rate of energy release. Because fire retardants are used to reduce both fire spread and combustion rate, it was concluded that both parameters must be considered in effectiveness evaluations. To determine the effects of retardant chemicals (ammonium phosphate and sulfate) on overall fuel flammability, George and Blakely (1972) burned treated ponderosa pine needle and aspen excelsior fuel beds with various amounts of chemical in an environmentally controlled wind tunnel. Results showed that the effectiveness was related to the type of chemical applied (its effectiveness depending on its thermal behavior characteristics and thus availability) and the distribution of the chemical within the fuel bed.

Applying the Rothermel spread model (Rothermel 1972) and using retardant effectiveness data(Rothermel and Philpot, in press), Swanson and Helvig (1973, 1974) also evaluated the effect of application concentration on fire spread. By converting the spread rate to Byram's intensity scale (Byram 1959), the reductions in intensity (knockdown) offered as a function of the amount of retardant applied can be estimated for several fuel situations. The Swanson-Helvig model utilizes the state-of-the-art in fuel description, rate-of-spread modeling, and determinations of retardant effectiveness. Refinement and verification of this model, however, will be required to incorporate retardant types, rheological properties, type of application (extinguishing or retardant action) as a function of the critical fuel, and other fuel and fire characteristics.

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[1]Contract 26-2888 by the Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, to Honeywell, Government and Aeronautical Products Division.

Current Research

Laboratory and field studies are underway and are planned that will refine and verify the Swanson-Helvig model by providing estimates for retardant requirements as a function of the type of fuel, fire, and method of application. The studies will quantify retardant effectiveness in several specific fuel types (grass, brush, timber, etc.) and fire situations. The effects of retardant distribution within the fuel complex will be determined through both laboratory and field tests.

Model inputs will be expanded to consider retardant effectiveness as a function of the mode of attack; i.e., quantify "extinguishing" and "retardant" effects separately and in combination and quantify the importance of retardant rheological properties in both operation modes. The final output will define retardant requirements as a function of the critical fuel in terms of optimum distribution for various fuel and fire situations so that the retardant chemical and rheological properties can be tailored for specific needs.

Continuing studies are evaluating the combustion retarding effectiveness of newly submitted retardant formulations according to qualification and evaluation procedures as outlined in current Forest Service specifications.

Laboratory studies will be conducted in cooperation with the fire retardant manufacturers and other research units at the Northern Forest Fire Laboratory. National Forest Systems, Bureau of Land Management, State fire management agencies, and the San Dimas Equipment Development Center (USDA Forest Service) may be involved in the field tests.

RETARDANT PHYSICAL PROPERTIES

Research Summary

For centuries, water has been used to extinguish fires on wildlands and in urban areas. Not until recently have chemicals been added to enhance the fire retarding and extinguishing qualities of water. Potential fire retardant chemicals were tested at the Forest Products Laboratory (Barrett 1931; Truax 1939; Tyner 1941) to improve the chemical effectiveness of water, but little was done to improve its physical properties.

With the advent of the operational use of aircraft for cascading fire retardant, it was apparent that considerable effort was warranted to alter the physical properties of the retardant in order to improve the delivery or drop characteristics and increase retardant retention on aerial fuels--especially when high winds and extreme drop heights were encountered, as often occurs in mountainous terrain and in difficult fire situations.

Miller and Wilson (1957) tested the use of a thickened sodium calcium borate as a suppressant and retardant for ground application and for aerial delivery. The drop characteristics of borates appeared superior to those of water. Borate had better coating and water-holding ability and seemed to have some long-term retarding effects. Disadvantages of borate were its corrosiveness, abrasiveness, toxicity to plants, and its difficult handling properties.

Davis (1959) showed the advantages of viscous water during drop tests of water and thickened water in comparative efforts to determine which gave the best ground distribution patterns and coverage on forest fuels. Phillips and Miller (1959) evaluated bentonite clay as a viscous agent and found that under severe drying conditions it did not remain effective as long as borate. However, they did note several operational advantages: bentonite weighed less, was cheaper, was less corrosive and abrasive, was nontoxic, and had drop characteristics similar to borate.

Johansen and Shimmel (1963) performed tests on and initiated the operational use o industrial gums and attapulgite clay as thickeners for water solutions of monoammonium phosphate and diammonium phosphate fire retardants. The thickened retardant solutions gave more concentrated ground distribution patterns and resulted in more retardant salt per unit area covered.

Aidun and Grove (1961), working for the Bureau of Yards and Docks, Department of the Navy, tested water thickened with industrial gums and bentonite clay and reported a marked increase in the fire knockdown or suppressing ability of thickened water. The results stimulated forest firefighting agencies to initiate further studies to determine the feasibility and possible advantages of adding gums and gels to water and water-chemical solutions for both ground and aerial application.

Davis and others (1962, 1965) tested water thickened with gels and gums on forest range, structural, and vehicle fires and found that much more plain water than viscous water was needed for the same extinguishment job. On one vehicle fire, plain water wa having little extinguishing effect, but thickened water put the fire out. Trout (1970 and Livingston (1972), working with thickened water for inside building sprinklers, showed the distinct advantage of larger droplets in penetrating the heat column and reaching the base of the flames. Results of these studies indicate that viscous agent which create larger droplets can provide greater effectiveness for ground and aerial applied forest fire retardants when used as extinguishing agents (direct attack situations).

Viscous agents were first incorporated in aerial and ground retardant formulation for the purpose of providing better adherence of the retardant to the fuels and to minimize the runoff. Davis (1959), George and Blakely (1973), and George (1975) recog nized several advantages of thickened retardant for aerial delivery: (1) greater shea resistance during breakup; (2) larger mean droplet sizes; and (3) less material lost t drift and evaporation. George and Blakely also noted superior drop characteristics we obtained for gum-thickened retardants as compared to clay-thickened and unthickened retardants.

Recent drop tests[2] conducted at Marana disclosed the importance of retardant rheological properties other than viscosity. Water thickened with guar gums, attapulgite clay, invert emulsion, and dilatants was dropped from the same tank system under simil environmental conditions. Although a variety of viscosities for each material were used (from 1,500 to 10,000+ centipoise for some materials), ground distribution patterns and movies of the drops showed that the gum-thickened retardants were eroded less by shearing forces during exit from the aircraft tanks and during freefall to the ground than the other retardants tested.

[2]A study of the effects of tank and gating characteristics on retardant ground distribution patterns, Study Plan 2107-17C, unpublished data on file at the Northern Forest Fire Laboratory, Missoula, Montana.

Because of the results from these tests, studies were undertaken to establish the relationship between the rheological properties of a fire retardant and its drop behavior, dispersion characteristics, and wetting-out properties (Andersen and others 1973, 1974a,b).[3] Andersen has developed analytical models to describe the aerodynamic breakup of aerially delivered fire retardant. These models, together with shock tube and gas gun experiments, indicated that the breakup characteristics of liquid retardants are influenced by the effective viscosity. The effective viscosity incorporates effects of fluid viscosity and fluid elasticity at the shear rate specified (effective viscosity is shear-rate dependent). It was shown that for gum-thickened retardants, breakup rate decreases and droplet size increases as the effective viscosity is increased. It was concluded that gum-thickened retardants are generally superior. Their elastic nature allows the maintenance of a high effective viscosity under shear rate conditions experienced during aerial drops. The large apparent viscosity of clay-thickened retardants is so reduced by shear that the resultant drop characteristics are similar to water or unthickened retardant.

Current Research

Laboratory and field tests have shown the importance of retardant rheological properties on the aerial breakup of the retardant and the resultant ground distribution pattern. The retardant rheological properties affect the mean droplet size and thus their velocity, trajectory, and consequently, the fuel wetting or coverage. Although general analytical models were developed to describe the aerodynamic breakup of retardant, the implications and predictions of the models in terms of effect of the many specific parameters on ground patterns have not been completely evaluated. Correlation of predicted and actual dissemination patterns is needed to make the best use of these models and obtain potential improvement by verifying or refining certain constants.

Past studies have also shown that the rheological properties of retardants have significant effects on fuel wetting by dynamic droplet impaction and on subsequent liquid storage by the fuel. Further studies are needed to develop analytical models that elucidate the important impact and fluid properties for impaction wetting and static film spread and storage within the vertical fuel complex.

Development and verification of models describing aerial breakup and retardant distribution within the vertical fuel as a function of retardant chemical-physical properties (including rheological properties) will provide the tools necessary to tailor the retardant to specific drop conditions and fire situations. The tailored formulation may be one based on trade-offs between optimum delivery characteristics and optimum distribution within the fuel complex or it may define a system allowing preselection of retardant properties for the conditions encountered.

Studies are presently being conducted (contract to Shock Hydrodynamics) to determine the retardant rheological properties affecting aerial breakup, formation of the retardant cloud, and resulting distribution within the fuel complex; i.e., those fuels considered most critical. These data will help to correlate rheological properties to droplet size distribution and actual dispersion patterns formed. Other studies are continuing to quantify the rheological properties of currently used retardants under the range of shear conditions encountered in actual retardant drops. Future studies will evaluate the effect of varying retardant rheological characteristics on distribution and retention in representative fuels.

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[3] Contract 26-3198 by the Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, to Shock-Hydrodynamics, Division of Whittaker Corporation.

RETARDANT DELIVERY SYSTEMS

Research Summary

Shortly after World War I, forest fire control agencies began to use aircraft for aerial patrol. In 1935, attempts were made to apply water to forest fires from a Ford Tri-motor by means of 8-gallon beer barrels, steel cans, and through a hose trailed behind the aircraft. Results of these and other tests (Headly 1943) were not promising and testing was not resumed until 1947. Hanson and Tebbe (1947) reported using P-47 and B-29 aircraft to drop exploding containers filled with water. Although partially successful, the system was discarded because of the danger to ground personnel.

In 1953, water was first freedropped, using a DC-7 tanker with a 2,400-gallon water-ballast-dump system (Operation Firestop 1955b). The test showed the practicality of cascading fire retardant on wildland fires. Also, during Operation Firestop, a 600-gallon tank was installed in a TBM and water was cascaded to determine ground pattern distributions. The patterns indicated adequate concentrations were attained and led to two successful drops on test fires.

The Firestop tests marked the beginning of the operational use of aerially delivered fire retardants. In 1956, Stearman aircraft with 150-gallon spray tanks and emergency dump doors were used successfully to cascade over 150,000 gallons of water and retardant on fires (Davis 1959). Since that time, many different types of aircraft have been equipped with tanks having up to 4,000 gallons capacity and have been used operationally with various degrees of success. The tank and gating systems in these aircraft, however, have remained essentially the same as those on the first TBM. Limited refinements have been made in the systems, mostly for safety or economy. Until recently, few attempts have been made to relate the tank configuration and door opening system to ground patterns.

Perhaps the most significant advance in retardant release systems has been the development of a pressurized dispensing system by Food Machinery Corporation under an Air Force contract (USAF 1973; George 1973). The pressure system is modular and is constructed so that it can be quickly loaded into a C-130 aircraft (presumably an Air Force, National Guard, or Reserve aircraft). The pressure system permits close regulation of flow rates, thus allowing patterns to be altered to meet specific fire situations.

MacPherson (1968) developed a theoretical model to estimate the width of the wetted area and to produce idealized contour patterns of retardant drops. His model predicted ground distribution patterns based on aircraft speed and altitude, tank geometry, door opening speed, and certain parameters of the retardant breakup process.

Static tests (flow rate) and aerial drop tests conducted by the Northern Forest Fire Laboratory (1973, 1974) indicated that the tank geometry, door opening size and speed, and venting affect retardant flow rates from the tanks and thus influence ground distribution patterns. The studies showed that patterns can be improved by designing the release system to minimize shear and breakup and by controlling retardant flow rates from the tank.

A contract was let to Honeywell Corporation (Contract 26-2888) to quantify critical parameters that can improve aerial delivery of retardants. Results of this contract (Swanson and Helvig 1973) indicated that the most efficient method of delivering retardant was by the conventional cascade method (other systems--containerized

lelivery, solid retardant [ice, etc.] were investigated). Utilizing analytical iodels of liquid breakup, the MacPherson model, and ground distribution patterns from revious quantified tank and gating systems, Swanson and Helvig developed an empirical etardant dispersion model. The model predicted ground distribution patterns as a unction of tank and gating system parameters and aircraft drop height and speed. ith few exceptions, correlations of predicted and actual retardant flow rates and round distribution patterns for various tank and gating systems revealed that if the etardant flow history from the tank is known it is possible to predict ground distri- ution patterns with reasonable accuracy.

Swanson and Helvig's model does not deal with the effect of fluid geometry and the ddition of individual tank increments dropped either simultaneously or in sequence. o obtain the data required to incorporate the effects of fluid geometry, drop spacing, nd retardant rheology, and to further refine the model, Swanson and Helvig recommended iat these parameters be studied independently and the results applied to designing timum tank and gating systems for specific aircraft and for specific fire situations.

Current Research

Research has shown that the retardant flow rate from the tank and rheological roperties govern the retardant breakup, cloud formation, and ground pattern. Quanti- cation of parameters influencing the flow rate and breakup will make possible the fining of models so that performance guidelines and tank and gate design specifica- ons can be written. The information needed will be gathered and utilized as follows:

1. Static testing of drop systems to quantify flow rates, door opening histories, d tank geometry, and to relate these data to deformation, breakup, dispersion, and ound patterns.

2. Develop and test an experimental tank and gating system (ETAGS) for determin- g the effect of tank and gating parameters, such as door opening speed, tank ometry, venting, clutter, exit areas, compartment separation, and retardant quantity.

3. Design, fabricate, test, and install an optimum tank and gating system (based information gathered from the test of the experimental tank and gating system) in appropriate aircraft; perform drop tests and then an operational evaluation. Tank nstruction costs may be developed from this study.

4. Use data from static testing to model responses of drop patterns to drop ight, airspeed, and type of retardant. Prepare user guidelines outlining the most fective use of existing air tankers in given situations.

5. Define the optimum tank and gating system for specific fire situations cording to the National Fire-Danger Rating System and Fire Spread Models) and for ious aircraft (tank and gating specifications).

6. Develop design information to be used by private contractors when tanking craft.

A contract has been let to Honeywell[4] to design, construct, and install an erimental tank and gate system in a Forest Service P2V aircraft. This contract iolves a subcontract to Aero Union Corporation, an air tanker contractor, and vides for cooperation with the air tanker industry. In addition, Honeywell currently contracted by the Forest Service to develop mission guidelines for several selected

[4]Contract 26-3425 by the Intermountain Forest and Range Experiment Station, North- Forest Fire Laboratory, to Honeywell, Government and Aeronautical Products Division.

aircraft.[5] Both contracts will provide information that is being utilized by the industry through the National Air Tanker Screening and Evaluation Board (the Board includes user agencies and air tanker contractors) and their established criteria.

Aerospace Corporation is cooperating in the ETAGS study by providing review of design analysis and by conducting structural analysis of critical components and subsystems.

RETARDANT-CAUSED CORROSION

Research Summary

Corrosion induced by retardants in air tankers and ground support equipment has been considered a problem since the very beginning of the retardant program (Operation Firestop 1955a). Retardant formulations without inhibitors were tested in 1964 for stress and fatigue corrosion on several metals commonly used in air tankers. The results showed that the retardants were corrosive in varying degrees, from failures within 2 days to only small pits after a year's time, depending on the retardant-metal combination examined (USDA Forest Service 1964).

After the 1964 fire season, a six-man task force examined a group of air tankers which had been used to carry several different types of retardant and found varying amounts of corrosion damage. The degree of damage was found to be related to the type of retardant carried, the type of metal used in the construction of the aircraft and tanks, the use of protective coatings, and the housekeeping practices of the operators. Methods for reducing the corrosion damage (Davis and Phillips 1965) were recommended. Early in 1968, tests were run on samples of retardants and aluminum alloy 2024-T3, using immersion tests and the Magna Corrater. On the basis of these tests it was recommended that the Magna Corrater be used as a preliminary test for corrosion on any new retardant product (USDA Forest Service 1968).

In 1969, the Forest Service issued specifications for both dry and liquid retardants (USDA Forest Service 1969b, 1970b) that outlined corrosion tests to be performed on aluminum alloy 2024-T3. Although other alloys have been corrosion tested (USDA Forest Service 1968 and 1969a), aluminum alloy 2024-T3 was chosen because it is the most critical material from the standpoint of aircraft safety. Since then, other metals and retardant formulations have been examined for corrosion using the Magna Corrater and other general corrosion rate techniques (USDA Forest Service 1970a; Bradford 1973). The last thorough inspection of equipment in contact with retardants was in 1965. Since that time, new formulations and equipment have come into use. The nature and magnitude of corrosion damage to this equipment must be quantified, including determination of the alloys that are susceptible to corrosion damage and the type of corrosion causing the damage. Laboratory tests can be performed for the various types of corrosion and results of these tests correlated with corrosion determined to be present in the field.

The Forest Service has awarded a contract to Ocean City Research Corporation to assess the corrosion effects of chemical retardant on mixing and delivery systems, particularly air tankers, and to determine the corrosion rates on critical alloys, and correlate these rates to actual field damage and recommend methods of reducing the corrosive effects (Contract 26-3250). By inspecting aircraft and reviewing

[5]Contract 26-3332 by the Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, to Honeywell, Government and Aeronautical Products Division

literature, the contractor has identified the 10 most common alloys used in air tankers and ground equipment, and the most corrosion-prone portions of mixing, handling, and delivery systems. Ten alloys and five retardants were tested for general corrosion rates by weight loss and linear polarization methods utilizing constant and alternate immersion exposures. Galvanic corrosion rates for the various metal-to-metal couples in the different retardants were determined. The stress corrosion of the metal-retardant combinations was determined using both U-bend and double cantilever beam methods; alloys that were susceptible to corrosion fatigue have been fatigue tested. The tendency of the alloys to localized corrosion was characterized as was the critical pitting potential at which passivity breaks down and pitting begins. Ten candidate protective coatings were selected and exposed to the retardants for 1 month. The three best coatings were then tested over long-term exposures. From the literature, 10 inhibitor candidates were selected and tested with each of the alloy-retardant combinations; the three most promising inhibitors were selected and subjected to galvanic, stress, fatigue, and general corrosion tests (Ocean City Research Corporation 1974).

Current Research

The corrosive effect of present and future retardant formulations must be controlled within safe and economical limits. Basic knowledge is being accumulated on the extent and types of retardant-caused corrosion. Corrosion problems are being identified by equipment manufacturers, aircraft contractors, or by fire control personnel associated with retardant mixing, handling, and delivery.

Engineers specializing in corrosion abatement are helping to establish general corrosion prevention guidelines. Guidelines may be implemented through design or performance requirements for retardants, mixing, handling, and delivery equipment, and the adoption of better housekeeping techniques.

The basic aim of current corrosion research is to:

1. Develop performance requirements which specify the permissible limits of critical types of corrosion acting on various alloys and performance tests. These performance requirements will be included in the specifications.

2. Design inhibitor systems that will restrict corrosion to permissible limits.

3. Establish user guidelines that cover corrosion-resistant alloys, inhibitors and protective coatings, and maintenance procedures.

Current studies are aimed at evaluating the corrosion characteristics of new retardant formulations on several alloys by means of electrochemical techniques, and examination of aircraft and mixing equipment to determine the extent of the problem, to identify alloys used, and the types of corrosion occurring. Laboratory tests are being conducted to determine corrosion characteristics and to correlate findings with actual damage. Ocean City Research Corporation is performing a major part of the corrosion studies and is preparing recommendations to aid retardant users.

Future studies will determine inhibitor depletion rate for various inhibitors, alloys, and retardant solutions. Inhibitors will be rated for reducing the potential of stress cracking and fatigue susceptibility. Corrosion rates will be determined relative to the type of inhibitor and concentration. Inhibitor combinations or systems will be evaluated to minimize corrosion to those alloys determined to be critical.

Studies will be conducted to correlate the results of corrosion tests using the Magna Corrater and tests for uniform, stress, fatigue, and galvanic corrosion, etc., performed by Ocean City Research Corporation. If a correlation can be obtained, the Magna Corrater will provide a simple method for screening and testing new inhibitor-containing formulations.

RETARDANT ENVIRONMENTAL IMPACT

Research Summary

The effect of forest firefighting chemicals on the environment has been a concern of fire control officials since the beginning of the retardant program. In 1955 when "Operation Firestop" (the program that pioneered aircraft-applied chemical retardant) was initiated, it was recognized that the toxicity of retardants must be tested (Operation Firestop 1955a). Field tests using sodium calcium borate were conducted in 1956 (Miller and Wilson 1957), but the toxic properties of the compound were overlooked in favor of its effectiveness. In 1958, laboratory and field tests of bentonite were undertaken, and the results appeared promising (Phillips and Miller 1959). One of the advantages of bentonite was that it was nontoxic to plants and animals. In subsequent years many other materials were tested, toxicity being a point of concern. In 1960, new materials including several diammonium phosphate (DAP) based formulation were evaluated (Davis and others 1961). The use of DAP formulations was soon followe by ammonium sulfate compounds--both showed many advantages over the previous material

Toxicity has not been considered a problem with ammonium phosphate and ammonium sulfate compounds because both materials have been commonly used agricultural fertilizers (Sauchelli 1964). In addition, ammonium phosphates have been used as a source of nitrogen and phosphorus in cattle rations, and where all the supplemental protein was provided through the compound, no adverse effect was found (Bell and others 1968)

Phos-Chek, a DAP-based retardant, was tested on mice and rabbits for skin and ey irritation, and oral toxicity.[6] The results indicated no adverse effects to mice whe fed up to 25,000 mg of Phos-Chek per kilogram of body weight. The chemical was found to be only a mild irritant to eyes or skin.

Fire retardants have been accused of causing nitrate poisoning in livestock. A study in 1970 (Dodge 1970) indicated that for retardant to cause nitrate poisoning it must be converted to nitrate by soil bacteria and taken up by plants which must be ingested by the cattle. Dodge also shows that the conversion of ammonia salts to nitrate by plants can happen only under special climatic conditions; the likelihood w less than from range or pastureland fertilization. Other evidence has also indicate that these compounds could fall in a nontoxic category.

Experience with ammonium sulfate and ammonium phosphate fire retardants in the past years has led to skepticism concerning the nontoxic effects of these chemicals, especially in regard to their effects on fish and aquatic life. Although there have been many reports of fish kill during this time, only a few have been documented. I 1966, a trout kill in Sonoma County, California, was reported when some retardant overshot the fireline and dropped into a small creek.[7] During the Swanson River Fir in Alaska in 1969, many salmon were killed near the fire on which nearly a third of million gallons of retardant had been used.[8] Although retardants have not been defi itely tied to the salmon kill, the possibility of retardants being the causal agent cannot be ruled out. The Ukiah California Rod and Gun Club blamed the California

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[6]Monsanto Company. Toxicological investigation of Phos-Chek 202. Report by Younger Laboratory to Monsanto, December 6, 1965, 7 p. On file at Northern Forest F Laboratory, Missoula, Montana.

[7]Memo to California State Forester, F. H. Raymond, July 14, 1966.

[8]Memo to Sport Fishing Institute, P. A. Douglas, from Alaska State Director, Bureau of Land Management, 1970.

Division of Forestry for creating a major pollution threat to the Russian River by allowing spillage and waste from a retardant plant to be swept into the river.[9] On February 24, 1970, in excess of 270 juvenile steelhead trout were reportedly killed by a fire retardant chemical. A number of other similar instances of detrimental retardant impact have been documented.

Past experience, then, indicates that fire retardants mainly affect the environment through impact on water quality, and subsequently fish and other aquatic life. With a knowledge of the constituents of currently used fire retardant compounds and a review of the literature, some inferences can be made as to the degree of toxicity of these retardants in relation to certain animals, freshwater fish, and aquatic life.[10]

Because of the complex nature of the problem and the antagonistic or synergistic effect of retardant ingredients, further laboratory tests concerning the threshold levels for the total compound were found necessary.

Three major fire retardant compounds are currently being used throughout the United States. The majority of this retardant (approximately 20 million gallons annually) is applied from fixed-wing aircraft, the remainder from ground tanker units or helitankers, so maximum utilization and control can be achieved. Because it is more likely to reach streams or lakes directly, aerially applied retardant is of primary concern in an evaluation of the effect of retardants on water quality.

Because diammonium phosphate, ammonium polyphosphate, ammonium sulfate, and attapulgite clay make up most of fire retardant formulations, the effects of these specific compounds were studied first.

The literature indicated that many of the ions were lethal to fish and other aquatic life at the concentrations in the undiluted retardant. Obviously, these concentrations will be reduced when these materials are placed in any stream or body of water. The concentrates nevertheless provide a starting point from which to evaluate possible toxic effects.

Because of widely varying test conditions, investigators disagree on the concentrations of retardant chemicals that are lethal to different fish. Only recently have methods of testing the effects of pollutants on fish been standardized. The term most commonly used and approved by fish toxicologists concerning the limiting or threshold levels for various chemicals is TLm, the median tolerance limit, or the amount of chemical required to kill 50 percent of the test species within a specified time, such as 24 or 48 hours. Information taken from various sources but summarized by McKee and Wolf (1963) as to the toxic levels (TLm) determined for specific ions and under given conditions for fish and other aquatic and marine life indicates that the threshold concentration for ammonia is many times lower than for any of the other components.

Studies by the National Marine Fisheries Service (Blahm and others 1972, 1974) supported these conclusions and have shown that the 24-hour TLm for Coho salmon and rainbow trout of varying ages are from 128 to 1,760 milligrams per liter of retardant depending upon the type of retardant, the pH of the water, and the age of the fish. The toxicity of each retardant was directly correlated with the concentration of the free ammonia (NH_3) in the retardant, which in turn was dependent upon the amount of ammonia (NH_4^+) contained in the retardant and the pH of the solution.

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[9]KXTV News, September 18, 1970; and memo to Department of Fish and Game from Director, Department of Conservation, Resources Agency of California, September 8, 1970.

[10]C. W. George, 1971. Partially completed literature review on the environmental impact of fire retardants. Unpublished report on file at Northern Forest Fire Laboratory, Missoula, Montana.

A study by the Bureau of Sport Fisheries and Wildlife using total retardant formulations has similarly shown that ammonia is the critical toxic component of the formulations for certain invertebrate aquatic organisms (freshwater shrimp) and egg-sac fry of Coho salmon and rainbow trout.[11]

Van Meter and Hardy (1975) developed a method of estimating the elapsed time or travel distance necessary for retardant to be diluted to nonlethal concentrations for a given size stream and amount of retardant. As more complete data on the toxicity of various retardants and their components become available, the effects of retardant on water quality and stream chemistry can be estimated with greater precisio

Current Research

A literature review and past experiences indicate that retardants can have a detrimental impact on water quality and aquatic life. The primary ingredient in current fire retardants responsible for this impact has been identified as ammonia. It is unlikely that effective and economical substitutes will be found, in the immediate future, for the ammonium fertilizer compounds currently being used in retardant formulations. Further studies quantifying impacts on the forest environment with emphasis on water quality are necessary to determine trade-offs between fire effects and retardant effects.

For retardant falling directly on surface water, Van Meter and Hardy have developed some relationships to permit calculating lethal concentrations and residence time. Retardant falling on hillsides away from streams will interact with the soil, thus individual components will travel at different rates. Components that reach a stream change organism communities, depending on concentrations, duration, and chemical form.

More in-depth studies are being conducted to quantify the entry, fate, and impact of fire retardants in and alongside forest streams. A cooperative study with Pacific Northwest Forest and Range Experiment Station is being conducted to determine the short- and long-term effects of parallel and cross-stream retardant drops on water quality, fish, and benthic organisms.[12] Concurrently, information will be gathered on leaching of retardant chemicals and their effects on plants and forest soils. Data will include the relative mobility of the various retardant chemicals due to leaching, overland flow of retardant chemicals during intense storms, and the effect on the mobilization of mature soil nutrients.

Other studies will determine the dilution rates of retardants dropped into various sized streams. Retardant concentrations will be a function of time after stream entry and the distance downstream from point of entry. Data will be gathered on the impact of retardants on aquatic life by measuring the initial concentration of retardant introduced into a stream and the effect of the retardant "slug" as it moves downstream and becomes diluted.

Continued studies and evaluations are being made to determine the toxicity of new fire retardants submitted for qualification under USDA specifications.

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[11] H. O. Sanders and W. W. Johnson, 1974. Bureau of Sport Fisheries and Wildlife Fish Pesticide Laboratory, Columbus, Missouri. Unpublished report on file at Northern Forest Fire Laboratory, Missoula, Montana.

[12] Study Plan 1602-54 "A plan for a study of the effects of streamside application of ammonia-based fire retardant on streamwater chemistry and benthic organisms." C. Hawkes and L. Norris, Pacific Northwest Forest and Range Experiment Station (4/74). Norris and others, "Progress report on the entry, fate, and impact of fire retardants forest streams." Pacific Northwest Forest and Range Experiment Station (2/74).

Data from current studies will be used in future studies to evaluate trade-offs between environmental effects of fire and the use of retardants.

SUMMARY

The flow chart in figure 2 summarizes the many parameters that must be quantified and considered to prescribe retardants for maximum effectiveness in specific situations and with optimum safety.

The retardant research program at the Northern Forest Fire Laboratory has been divided into five study areas: effectiveness, physical properties, delivery systems, corrosion, and environmental impact. Within each study several substudies are being performed in-house, by contractors, and in cooperation with other agencies. Figure 3 shows the time lines for studies planned for the next 5 years and the organization that will conduct each study.

Retardant effectiveness studies are designed to determine the optimum amounts of chemical required to penetrate and coat the critical elements of the fuel complex and retard or extinguish flaming and glowing combustion.

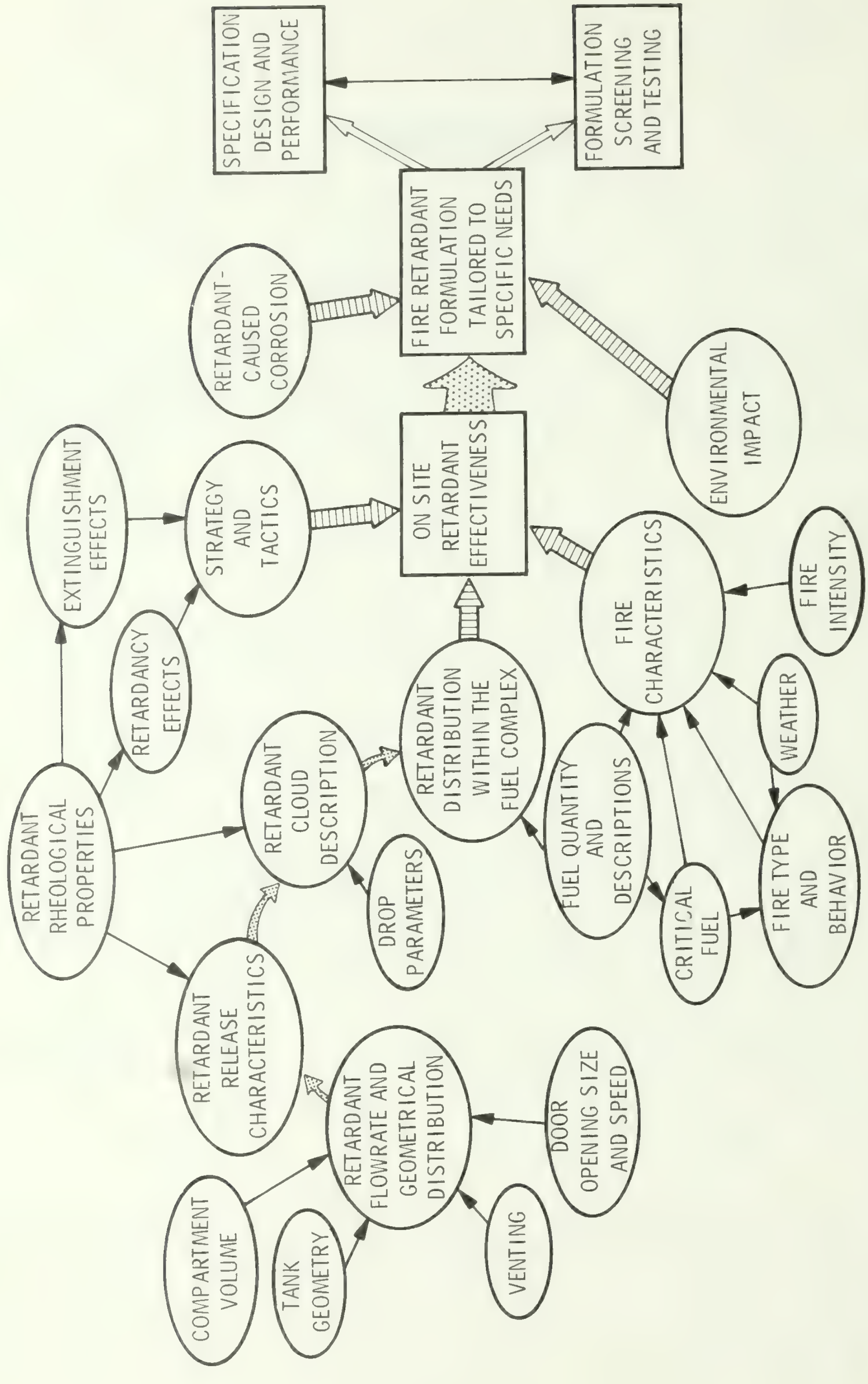
Examination and quantification of the physical properties of retardant formulations provide data that define the effects of retardant rheological properties on aerial breakup and resulting distribution within the fuel complex. The data are also used to correlate and formulate retardants to specific needs.

Research to quantify the effects of wind, tank and gating parameters, and drop height and speed on the deformation, breakup, dispersion, and final ground distribution patterns is providing criteria to design tank and gate systems for specific needs and for more effective usage by operating personnel.

Corrosion problems have been identified by equipment manufacturers, aircraft contractors, and fire control personnel associated with retardant mixing, handling, and delivery operations. Types of corrosion, the causes, and methods for minimizing the damage are described. Studies are continuing to quantify the effects of combinations of inhibitors, the effective lifetime of inhibitors, and the causes of various kinds of corrosion and how it can be minimized.

Studies indicate that ammonia is the retardant agent toxic to stream life. The extent to which fish and other organisms are affected is determined by the residence time of high ammonia concentrations. Lethal levels vary greatly and are related to fish species, age, and size. Continued research is quantifying impacts on forest flora, soils, fish, and other organisms so that the environmental effects of fire can be weighed against the impacts of retardants.

Cooperators and contractors participating with the Northern Forest Fire Laboratory in the studies are: Pacific Northwest Forest and Range Experiment Station; National Forest Systems; Bureau of Land Management; National Marine Fisheries Service; California Division of Forestry; Honeywell Corporation; Aerospace Corporation; Aero-Union; Ocean City Research Corporation; and Shock Hydrodynamics Corporation.



SPECIFICATION DESIGN AND PERFORMANCE
FORMULATION SCREENING AND TESTING
FIRE RETARDANT FORMULATION TAILORED TO SPECIFIC NEEDS
RETARDANT-CAUSED CORROSION
ENVIRONMENTAL IMPACT
ON SITE RETARDANT EFFECTIVENESS
EXTINGUISHMENT EFFECTS
STRATEGY AND TACTICS
RETARDANCY EFFECTS
FIRE CHARACTERISTICS
FIRE INTENSITY
WEATHER
FIRE TYPE AND BEHAVIOR
CRITICAL FUEL
FUEL QUANTITY AND DESCRIPTIONS
RETARDANT DISTRIBUTION WITHIN THE FUEL COMPLEX
RETARDANT CLOUD DESCRIPTION
DROP PARAMETERS
RETARDANT RHEOLOGICAL PROPERTIES
RETARDANT RELEASE CHARACTERISTICS
RETARDANT FLOWRATE AND GEOMETRICAL DISTRIBUTION
DOOR OPENING SIZE AND SPEED
VENTING
TANK GEOMETRY
COMPARTMENT VOLUME

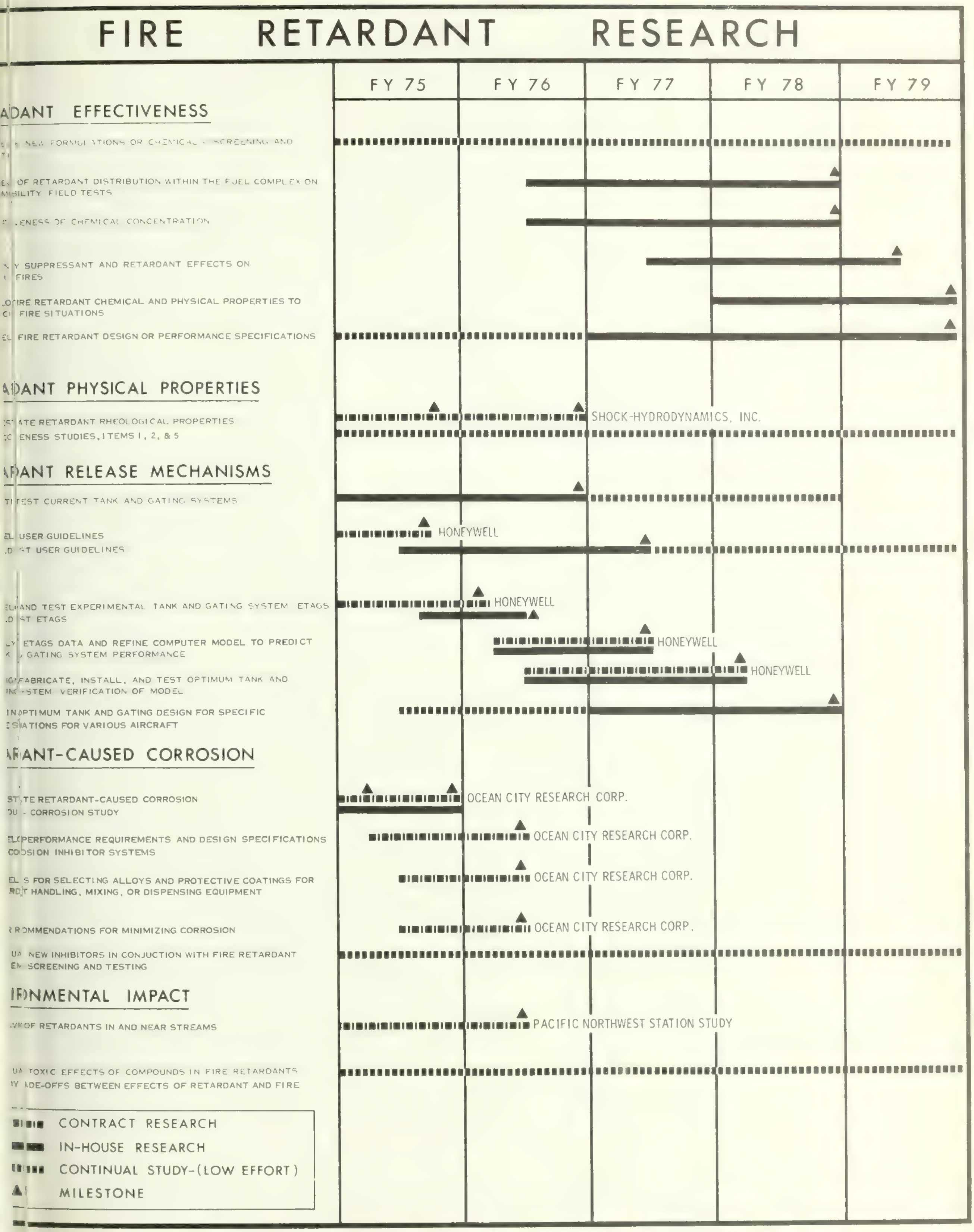


Figure 3.--Fire retardant research time line.

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☆ U.S GOVERNMENT PRINTING OFFICE:1976-O-677-328/65

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AMERICAN REVOLUTION BICENTENNIAL 1776-1976

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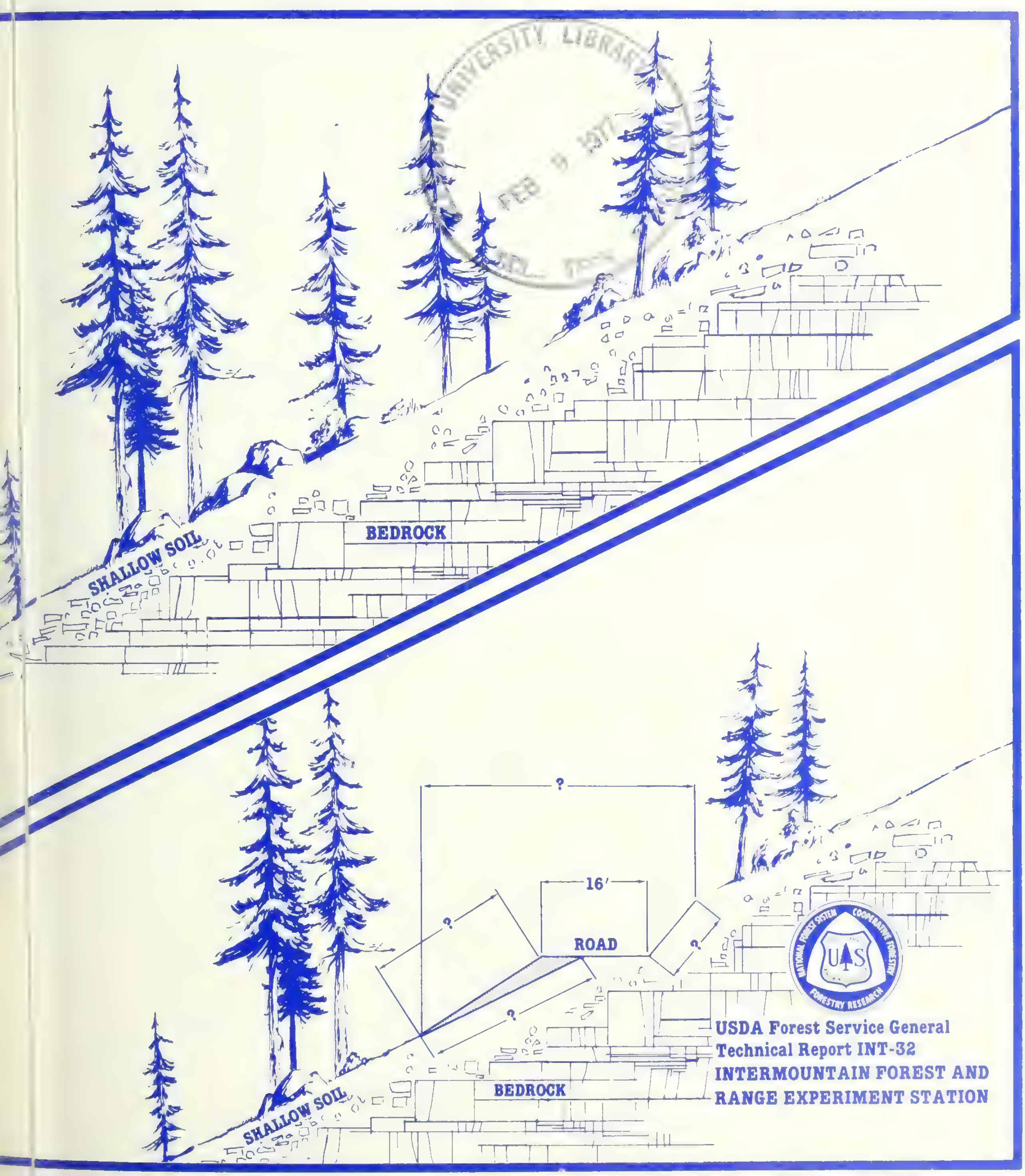
TABLES OF GEOMETRY FOR LOW-STANDARD ROADS FOR WATERSHED MANAGEMENT CONSIDERATIONS, SLOPE STAKING, AND END AREAS

Walter F. Megahan



USDA Forest Service General Technical Report INT-32
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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ABSTRACT

Tables were developed to provide various dimensions for low-standard roads built with a "balanced" construction technique. The information is intended to provide a means of evaluating potential watershed impacts of road construction and of helping to plan for appropriate corrective actions. Additional dimensions are provided to assist in slope staking and for estimating excavation volumes. The information has application in both the road location and design phases of the road construction process. The tables are for use in situations where low road costs preclude detailed engineering design or where engineering talents are simply unavailable.

INTRODUCTION

Thousands of miles of roads are built each year on private, State, and Federal Frest lands. Much of this annual construction consists of low-standard roads. These e low-cost roads receiving little or no engineering design either because the low ad cost precludes more detailed engineering design or simply because no engineering lents are available.

Unfortunately, any type of road construction creates a variety of site disturb- ces that tend to accelerate erosion, which in turn may increase downstream sedimen- tion (Anderson 1954; Fredriksen 1970; Haupt and Kidd 1965). Low standard roads are ten particularly troublesome because of such factors as poor location and design and k of erosion control measures. Numerous other researchers have documented the currence of increased sedimentation following road construction, especially in eper terrain (Megahan and Kidd 1972; Reinhart and others 1963; Rice and Wallis 52). Such effects have become more important in recent years because of the ctment of Federal and State laws to regulate pollution by sediments from diffuse rces including roads.

Most of the potential impact is caused by accelerated on-site erosion including h surface and mass erosion (landslides). Some possible causal factors include:

1. Removal or reduction of protective cover;

2. Destruction or impairment of natural soil structure and fertility;

3. Decreased infiltration rates on parts of the road;

4. Concentration of generated or intercepted water;

5. Interception of subsurface flow levels by the road cut slope;

6. Decreased shear strength, increased shear stress on cut and fill slopes, or both;

7. Increased slope gradients on cut and fill slopes.

last three factors are a direct result of the fact that road construction alters geometry of the hill slope.

The primary purpose of the road geometry tables presented here is to provide a means of estimating the extent of alteration of hill slope geometry before constructio Use of the tables makes it possible to evaluate potential watershed impacts and to plan appropriate corrective actions. Such questions as:

1. How much area is disturbed by road construction?

2. What is the area of the rainfall intercepting surface?

3. What is the area of fill and cut slopes needing stabilization treatment?

4. Will channel encroachment occur?

5. How much area is available to buffer sediment flow into a stream channel?

These and other questions can be answered if various dimensions of the road prism are known.

Additional road prism dimensions are included for individuals concerned with slope staking and end areas. This information is included for three reasons:

1. Slope staking is needed to guide operators during construction so that the proper road prism dimensions are obtained;

2. Some of the dimensions needed for slope staking are already available from the calculations dealing with watershed management considerations;

3. A commonly used reference table for slope stakes and end areas for minor roads (USDA Forest Service and USDI Bureau of Land Management 1967) is out print and is becoming generally unavailable.

ROAD PRISM DIMENSIONS CONSIDERED

The road prism dimensions pertinent to watershed management considerations are illustrated in figure 1. A description of the dimensions and some possible uses are:

1. SF = The slope distance from the grade daylight stake to the toe of the fill slope--

    a. Provides a means of determining possible channel encroachment.

    b. Defines the lower extremity of disturbed soil if channel encroachment does not occur; the distance from this point to the stream channel is the buffer strip that is available to trap eroded material. This information, coupled with guides for establishing the width of buffer strip (Ohlander 1976; Packer 1967; Trimble and Sartz 1957), provides a means of reducing sediment delivery to stream channels.

    c. Indicates the hazard for "sliver" fills. A sliver fill is a fill constructed on a hill slope where the hill slope gradient approaches or exceeds the gradient of the road fill slope. When this happens no fill embankment can form; instead, the fill material flows down the hill in a long sliver. This tendency is apparent in the tables; as the hill slope gradients approach the fill slope gradient of 1-1/2:1 (66-2/3 percent), the values for SF increase rapidly indicating increasing probability of sliver fills. The tables do not exceed 66 percent because the values for SF go to infinity beyond this point.

2. SC = Slope distance from the grade daylight stake to the top of the cut slope--defines the limit of upslope disturbance and possible uphill encroachment (for example, into upslope landslide areas).

3. WH = Total width of disturbance projected to a horizontal plane--defines the total width of the rainfall intercepting surface.

4. WS = Total width of disturbance along the hill slope--defines the total width of the disturbed surface available for erosion.

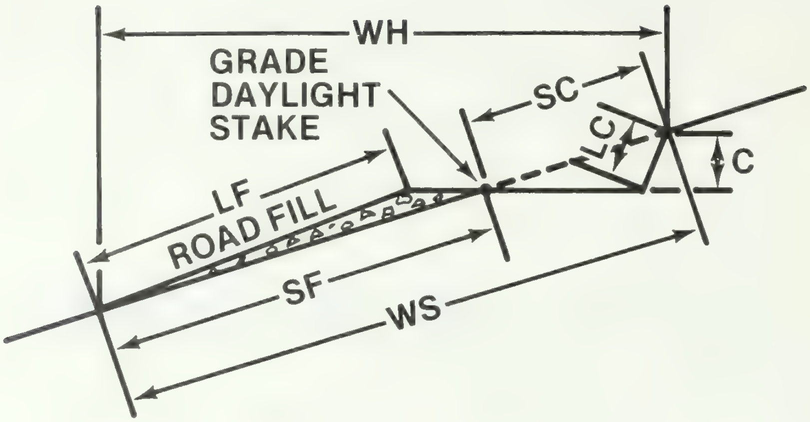

Figure 1.--Road prism dimensions for watershed management considerations.

5. LF = Length of the fill slope--

    a. Useful for determining slope stabilization needs.

    b. Often in combination with slope gradient is a useful parameter for estimating erosion by various procedures.

6. LC = Length of the cut slope--same uses as the length of fill slope.

7. C = Height of the cut, coupled with some knowledge of subsurface condition (for example, soil depth or ground water depth), helps--

    a. To indicate the potential for intercepting subsurface flow zones,

    b. To red flag possible slope stability problems.

The road prism dimensions for slope staking and end areas are shown in figure 2. Descriptions and uses of the dimensions are:

1. SF = The slope distance from the grade daylight stake to the fill stake--determines the location of the fill stake.

2. SC = The slope distance from the grade daylight stake to the cut stake--determines the location of the cut stake.

3. C = The height of the cut--to be marked on the cut stake.

4. HC = The horizontal distance from the cut stake to the road centerline--to be marked on the cut stake.

5. F = The height of the fill--to be marked on the fill stake.

6. HF = The horizontal distance from the fill stake to the road centerline--to be marked on the fill stake.

7. A = End area, in square feet, of the cut section--to obtain cubic yardage per 100 feet of road length by multiplying average end area by 3.7.

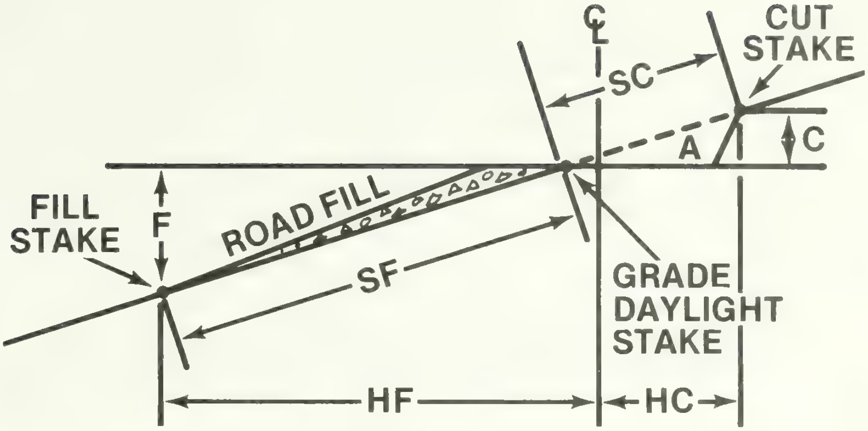

Figure 2.--Road prism dimensions for slope stakes and end areas.

DEVELOPMENT OF THE TABLES

The road geometry tables in the appendix were developed using hill slope gradient (θ_s), road width (W), and the gradient of the road cut (θ_c) and fill slopes (θ_f) as input variables (fig. 3).

Normally, these dimensions are known or can be closely estimated for a given situation. The most commonly used fill slope gradient on forest roads is 1.5 to 1; in the interest of economy, this is the only fill slope gradient given in the tables. Cut slope gradients of 1.5 to 1, 1.0 to 1, 0.75 to 1, 0.50 to 1, 0.25 to 1, 0.10 to 1, and vertical are presented. Hill slope gradients ranging from 10 to 66 percent are given in increments of 2 percent. Finally, road widths varying from 8 to 20 feet are given by 1-foot increments. The mathematical derivations are presented in the appendix so users can develop other combinations as needed. Calculations were programed in FORTRAN for a CDC 6600 computer; the program is available for use elsewhere.

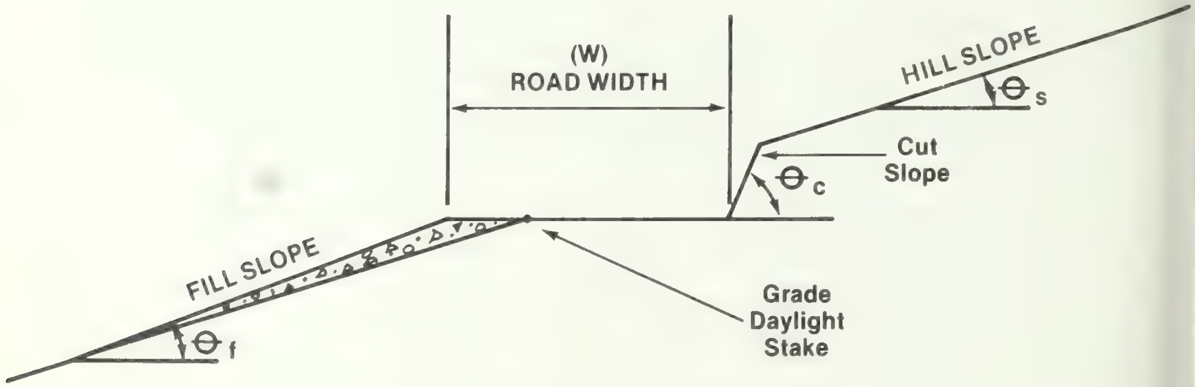

Figure 3.--Dimensions required for road geometry tables.

The following assumptions were made in the development of the tables:

1. *A "balanced" cut and fill is used for construction.* Low-standard roads are commonly built by using balanced construction. This requires that the volume of material cut out of the hillside be equal to the volume of material used to construct the fill portion of the road. This type of construction is commensurate with low road standards because it minimizes excavation costs and because the low road standards permit fitting the road closely to the terrain (a requirement if balanced construction is to be used). Obviously, for economic reasons balanced construction can be just as desirable for roads built to higher standards. Unfortunately, this is not often possible except in areas of fairly uniform terrain. Elsewhere, horizontal and vertical irregularities prevent balanced construction and the use of these tables.

2. *On the average, the fill section contains 15 percent less area than the cut section.* This adjustment factor is necessary because many times variations in topography, type of materials, construction methods, or other situations prevent truly balanced construction. There can be more or less area in the fill slope than in the cut slope; however, there is generally less area in the fill slope because of problems during construction, such as downslope losses of materials. A shrinkage factor of 15 percent was assumed as an average value most applicable for low-standard roads. The adjustment factor is introduced in step 6 of the appendix as a value K; this value can be varied if necessary for other situations.

3. *Slope gradients for cut slopes, fill slopes, and the hillside are relatively uniform.* With proper construction, cut and fill slope gradients should be uniform. If the hillside gradient is relatively uniform, an average gradient for the section of slope in question may be used.

4. *The road surface is horizontal.* Many times roadbeds are insloped or outsloped to reduce erosion. However, the amount of slope is usually only a few percent and should cause only minor inaccuracies.

5. *Cut and fill slope gradients are constructed as planned.* Lack of compliance to planned cut and fill slope gradients can cause large errors in road prism dimensions. Obviously, this can only be prevented by careful adherence to plans during construction. Slope staking should help the operator meet specifications. It should be pointed out that fill slopes constructed by sidecasting (common on low-standard roads) may have a steeper gradient than 1.5 to 1 immediately after construction. Consequently the fill slope will not extend as far downslope as expected. However, over time, such an over-steepened fill slope tends to adjust to a 1.5 to 1 gradient and so meet the planned dimensions.

Except for situations where "balanced" construction is not used or where large irregularities in the hill slope gradients occur, minor deviations from the five assumptions above should cause only minor inaccuracies in road prism dimensions. The tables are only applicable to balanced construction and should only be used for this purpose. Where minor irregularities in the hill slope gradient occur, an average slope may be used without introducing large errors. However, as hill slope irregularities become large or as gradients approach 66 percent, large errors can be introduced. In this case, use good judgment to estimate what effect the break in hill slope gradient will have or use more intensive engineering design procedures to accurately cross-section the slope in question.

USE OF THE TABLES

Three factors must be known to use the tables: (1) road width, (2) cut slope gradient, and (3) hill slope gradient. A fourth factor, the fill slope gradient, is assumed to be 1.5 to 1 for all situations. A basic principle for minimizing watershed impacts from road construction is to minimize the amount of soil disturbance. This ca be accomplished by selecting the narrowest road width possible and the steepest cut slope possible. However, selection must be tempered by user needs in the case of road width and by slope-stability requirements in the case of cut slope gradients. General selection of road width is readily apparent depending on proposed road use; selection of cut slope gradients may require consultation with local expertise familiar with slope-stability problems in the area. The hill slope gradients are measured on site and used subject to the constraints discussed above.

Use of the tables also requires that a route location be available or assumed to serve as a reference point for measurements. This location is assumed to be a gradeli and is shown as the grade daylight stake on figures 1 and 2. Many times, the route location is established and the tables are used for slope staking and to help design stabilization needs. However, the tables are also helpful in selecting optimum route locations in areas where watershed management considerations are important. In this situation, a gradeline location is assumed and the road prism dimensions are determine These are then compared to the actual conditions on the ground to appraise potential watershed impacts. Oftentimes, severe impacts become apparent that require a change road location.

All dimensions in the tables are in feet except the end area, which is in square feet. The tables are suitable for roads that have additional width requirements for berm or ditch. Simply add the additional horizontal distance caused by the berm or ditch to the basic road width and use the total width to enter the tables.

An example: watershed management considerations

As indicated above, the tables have a variety of potential uses for watershed management purposes. An example follows:

Given:
1. A 200-foot-long section of road located near an important fishing stre
2. Road width = 10 feet
3. Cut slope gradient = 1 to 1
4. Hill slope gradient = 50 percent
5. Slope distance from the grade daylight stake to the stream = 50 feet

Find: How can watershed impacts on the stream be minimized?

The first question would probably be "Will the road fill encroach on the stream Referring to the tables, we find that the slope distance from the grade daylight sta to the toe of the fill slope (SF on fig. 1) will be about 18 feet; so direct stream encroachment will not occur. However, this slope distance allows only 32 feet between the road fill and the stream, a distance that is judged to be inadequate after refer to guides for size of buffer area (Ohlander 1976; Packer 1967; Trimble and Sartz 195 It is not practical to change the road location, but two alternatives are possible: (1) Improve the efficiency of the buffer strip by adding materials to help store ero material en route to the stream; or (2) control the erosion at the source by intensi

osion-control measures. This particular stream is very valuable; so both courses of tion are taken. The decision is made to augment sediment storage with the use of gging slash lopped and placed below the fill slope to assure close contact with the il surface. On-site erosion control consists of mulching both cut and fill slopes and ansplanting trees into the fill slope to help protect against mass erosion. Reference to the tables shows that the fill slope will be about 15 feet long (LF on fig. 1) d the cut slope will be about 9 feet long (LC on fig. 1). The total of these two gures times the length of road involved (200 feet in this case) indicates a need for lching 4,800 square feet or about 0.1 acre. Planting trees at a 4- by 4-foot spacing the 15- by 200-foot fill slope will require about 190 transplants.

example: slope staking

Referring to figure 2, slope staking proceeds as follows using stations located 100-foot intervals along the road. (If slope staking efforts must be curtailed, nsider installing cut stakes only.)

1. Locate the position of the cut and fill stakes by determining the slope distance from the grade daylight stake to the slope stakes (SC for the cut stake and SF for the fill stake).
2. Determine the amount of vertical cut (C) or fill (F); and record on the cut and fill stakes, respectively.
3. Determine the horizontal distance from the slope stakes to the road centerline (HC for the cut stake and HF for the fill stake). Record on the cut and fill stakes, respectively.
4. Record the above dimensions along with the gradients of the cut and fill on the stakes. The cut and fill stakes for the hypothetical road dimensions given in the example above would appear as shown in figure 4.

As a point of interest, reference to the end area dimensions in the tables shows t the road section presented in the example on page 8 will require excavation of ut 135 cubic yards of material.

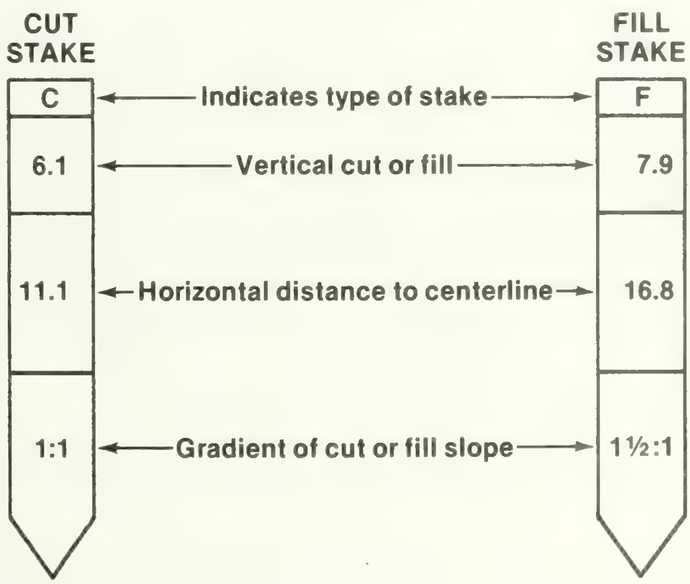

Figure 4.--Dimensions for marking cut and fill stakes.

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APPENDIX

Procedure to calculate road prism geometry given the dimensions in figure 3:

W = Width of road (feet)

θ_c = Angle of cut slope (degrees)

θ_f = Angle of fill slope (degrees)

θ_s = Angle of hill slope (degrees)

Calculate horizontal distance from gradeline to top of cut slope per foot of cut width (C_h), where cut width is the distance from the grade daylight stake to the toe of the cut slope:

$$C_h = \frac{\text{Tan } \theta_c}{\text{Tan } \theta_c - \text{Tan } \theta_s}$$

2 Calculate slope distance from gradeline to top of cut slope per foot of cut width (C_s):

$$C_s = \frac{C_h}{\text{Cos } \theta_s}$$

3 Calculate horizontal distance from gradeline to bottom of fill slope per foot of fill width (F_h), where fill width is the distance from the grade daylight stake to the top of the fill slope:

$$F_h = \frac{\text{Tan } \theta_f}{\text{Tan } \theta_f - \text{Tan } \theta_s}$$

4 Calculate slope distance from gradeline to bottom of fill slope per foot of fill width (F_s):

$$F_s = \frac{F_h}{\text{Cos } \theta_s}$$

5. Calculate the end area of the cut section for a unit cut width of 1 foot (A')

$$A' = 0.5 * C_s * \text{Sin}\ \theta_s$$

6. Assuming an equal area for the fill section times a correction factor (1+K) to account for shrinkage during construction, calculate the width of the fill corresponding to the unit width of the cut (W_f'). An average 15 percent shrinkage loss was assumed for the tables; so a value of -0.15 was assigned to K in the development of these tables. Other K values can be applied as needed:

$$W_{f'} = \left[\frac{(1+K) * C_s}{F_s}\right]^{0.5} = \left[\frac{(0.85) * C_s}{F_s}\right]^{0.5}$$

7. Calculate the total cut width (B):

$$B = \frac{W}{1.0 + W_f'}$$

8. Calculate the total fill width (W_f):

$$W_f = W - B$$

9. Calculate the horizontal distance from the grade daylight stake to the road centerline (D):

$$D = B - 0.5 * W$$

10. Calculate the horizontal distance from the centerline to the cut stake (HC):

$$HC = C_h * B - D$$

11. Calculate the horizontal distance from the centerline to the fill stake (HF):

$$HF = F_h * W_f + D$$

12. Calculate slope distance from the gradeline to the toe of the fill (SF):

$$SF = F_s * W_f$$

13. Calculate slope distance from the gradeline to the top of the cut (SC):

$$SC = C_s * B$$

14. Calculate the total horizontal distance disturbed (WH):

$$WH = F_h * W_f + C_h * B$$

5. Calculate the total slope distance disturbed (WS):

$$WS = SF + SC$$

6. Calculate length of fill slope (LF):

$$LF = \frac{W_f * (F_h - 1)}{\cos \theta_f}$$

7. Calculate length of cut slope (LC):

$$LC = \frac{B * (C_h - 1)}{\cos \theta_c}$$

8. Calculate end area (A):

$$A = A' * B^2$$

9. Calculate cut height (C):

$$C = \sin \theta_s * SC$$

10. Calculate fill height (F):

$$F = \sin \theta_s * SF$$

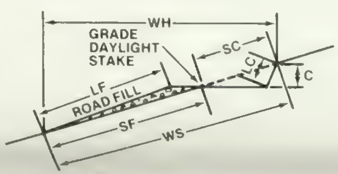
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 8 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.3	4.3	8.6	8.7	.8	.4	.4	4.0	.4	4.6	.9
12	4.5	4.4	8.8	8.9	1.0	.5	.5	4.0	.5	4.8	1.1
14	4.6	4.4	9.0	9.0	1.2	.6	.6	4.0	.6	5.0	1.4
16	4.8	4.5	9.1	9.2	1.4	.7	.7	4.0	.8	5.1	1.6
18	4.9	4.5	9.3	9.5	1.6	.8	.8	4.0	.9	5.3	1.8
20	5.1	4.6	9.5	9.7	1.8	.9	.9	4.0	1.0	5.5	2.0
22	5.3	4.7	9.7	9.9	2.0	1.0	1.0	4.0	1.1	5.7	2.3
24	5.5	4.7	9.9	10.2	2.3	1.1	1.1	4.0	1.3	5.9	2.5
26	5.7	4.8	10.1	10.5	2.6	1.2	1.2	4.0	1.4	6.1	2.8
28	5.9	4.9	10.4	10.8	2.9	1.3	1.3	4.0	1.6	6.4	3.1
30	6.2	5.0	10.7	11.1	3.2	1.4	1.4	4.0	1.8	6.7	3.4
32	6.5	5.0	10.9	11.5	3.5	1.5	1.5	4.0	2.0	6.9	3.7
34	6.8	5.1	11.3	11.9	3.9	1.7	1.7	4.0	2.2	7.3	4.0
36	7.1	5.2	11.6	12.3	4.3	1.8	1.8	4.0	2.4	7.6	4.4
38	7.5	5.3	12.0	12.8	4.8	1.9	1.9	4.0	2.7	8.0	4.7
40	7.9	5.4	12.4	13.4	5.3	2.0	2.0	4.0	2.9	8.4	5.1
42	8.4	5.6	12.9	14.0	5.9	2.2	2.2	4.0	3.3	8.9	5.5
44	9.0	5.7	13.4	14.7	6.5	2.3	2.3	4.0	3.6	9.4	6.0
46	9.6	5.8	14.0	15.5	7.3	2.4	2.4	4.0	4.0	10.0	6.4
48	10.4	6.0	14.7	16.4	8.1	2.6	2.6	4.0	4.5	10.7	6.9
50	11.3	6.1	15.6	17.4	9.1	2.7	2.7	4.0	5.0	11.6	7.5
52	12.4	6.3	16.6	18.7	10.3	2.9	2.9	4.0	5.7	12.6	8.1
54	13.7	6.5	17.8	20.2	11.8	3.1	3.1	4.0	6.5	13.8	8.8
56	15.4	6.7	19.3	22.1	13.6	3.3	3.3	4.0	7.5	15.3	9.6
58	17.7	6.9	21.4	24.7	16.1	3.5	3.5	4.0	8.9	17.4	10.5
60	21.1	7.2	24.3	28.3	19.5	3.7	3.7	4.0	10.8	20.3	11.5
62	26.4	7.6	28.8	33.9	25.0	4.0	4.0	4.0	13.9	24.8	12.8
64	37.0	8.0	37.9	45.0	35.9	4.3	4.3	4.0	19.9	33.0	14.6
66	80.9	8.8	74.9	89.7	80.3	4.8	4.8	4.0	44.6	70.9	17.7

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
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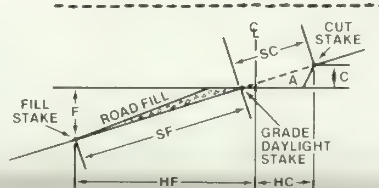
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

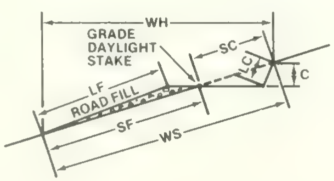
…DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 8 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.4	4.4	8.7	8.7	.8	.4	.4	4.0	.4	4.7	.9
12	4.5	4.4	8.9	8.9	1.0	.5	.5	4.1	.5	4.8	1.1
14	4.6	4.5	9.0	9.1	1.2	.6	.6	4.1	.6	5.0	1.4
16	4.8	4.5	9.2	9.3	1.4	.7	.7	4.1	.8	5.1	1.6
18	4.9	4.6	9.4	9.5	1.6	.8	.8	4.1	.9	5.3	1.8
20	5.1	4.7	9.6	9.8	1.8	.9	.9	4.1	1.0	5.5	2.1
22	5.3	4.8	9.8	10.0	2.0	1.0	1.0	4.1	1.1	5.7	2.3
24	5.5	4.8	10.0	10.3	2.3	1.1	1.1	4.1	1.3	5.9	2.6
26	5.7	4.9	10.3	10.6	2.6	1.2	1.2	4.1	1.4	6.2	2.9
28	6.0	5.0	10.5	10.9	2.9	1.4	1.3	4.1	1.6	6.4	3.1
30	6.2	5.1	10.8	11.3	3.2	1.5	1.5	4.1	1.8	6.7	3.4
32	6.5	5.2	11.1	11.7	3.6	1.6	1.6	4.2	2.0	7.0	3.8
34	6.8	5.3	11.5	12.1	4.0	1.7	1.7	4.2	2.2	7.3	4.1
36	7.2	5.4	11.8	12.6	4.4	1.8	1.8	4.2	2.4	7.7	4.5
38	7.6	5.5	12.2	13.1	4.9	2.0	2.0	4.2	2.7	8.0	4.8
40	8.0	5.6	12.7	13.7	5.4	2.1	2.1	4.2	3.0	8.5	5.2
42	8.5	5.8	13.2	14.3	6.0	2.2	2.2	4.2	3.3	9.0	5.7
44	9.1	5.9	13.7	15.0	6.6	2.4	2.4	4.2	3.7	9.5	6.1
46	9.8	6.1	14.4	15.8	7.4	2.5	2.5	4.3	4.1	10.1	6.6
48	10.6	6.2	15.1	16.8	8.2	2.7	2.7	4.3	4.6	10.9	7.2
50	11.5	6.4	16.0	17.9	9.3	2.9	2.9	4.3	5.1	11.7	7.8
52	12.6	6.6	17.0	19.2	10.5	3.1	3.0	4.3	5.8	12.7	8.4
54	14.0	6.8	18.3	20.8	12.0	3.2	3.2	4.3	6.6	14.0	9.1
56	15.8	7.0	19.9	22.8	13.9	3.5	3.4	4.3	7.7	15.6	10.0
58	18.1	7.3	22.0	25.5	16.4	3.7	3.7	4.4	9.1	17.7	10.9
60	21.6	7.6	25.0	29.2	20.0	3.9	3.9	4.4	11.1	20.6	12.1
62	27.1	8.0	29.8	35.1	25.7	4.2	4.2	4.4	14.3	25.4	13.5
64	38.0	8.5	39.2	46.5	36.9	4.6	4.6	4.5	20.5	34.7	15.4
66	83.5	9.4	77.5	92.8	82.9	5.2	5.2	4.5	46.0	73.0	18.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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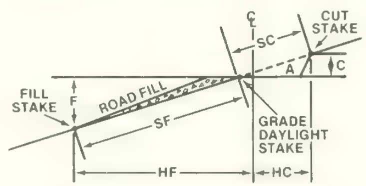
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

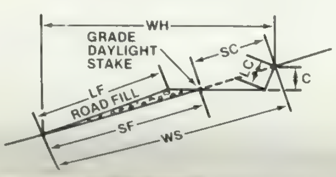
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 8 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.4	4.4	8.8	8.8	.8	.5	.4	4.1	.4	4.7	.9
12	4.5	4.5	8.9	9.0	1.0	.6	.5	4.1	.5	4.8	1.2
14	4.7	4.6	9.1	9.2	1.2	.7	.6	4.2	.6	5.0	1.4
16	4.8	4.6	9.3	9.4	1.4	.8	.7	4.2	.8	5.1	1.6
18	5.0	4.7	9.5	9.7	1.6	.9	.8	4.2	.9	5.3	1.8
20	5.1	4.8	9.7	9.9	1.8	1.0	.9	4.2	1.0	5.5	2.1
22	5.3	4.9	10.0	10.2	2.1	1.1	1.0	4.3	1.1	5.7	2.4
24	5.6	5.0	10.2	10.5	2.3	1.2	1.2	4.3	1.3	5.9	2.6
26	5.8	5.1	10.5	10.9	2.6	1.3	1.3	4.3	1.5	6.2	2.9
28	6.0	5.2	10.8	11.2	2.9	1.4	1.4	4.3	1.6	6.4	3.2
30	6.3	5.3	11.1	11.6	3.3	1.6	1.5	4.4	1.8	6.7	3.5
32	6.6	5.4	11.4	12.0	3.6	1.7	1.6	4.4	2.0	7.0	3.9
34	6.9	5.5	11.8	12.5	4.0	1.8	1.8	4.4	2.2	7.4	4.2
36	7.3	5.6	12.2	13.0	4.5	2.0	1.9	4.5	2.5	7.7	4.6
38	7.7	5.8	12.6	13.5	5.0	2.1	2.1	4.5	2.7	8.1	5.0
40	8.2	5.9	13.1	14.1	5.5	2.3	2.2	4.6	3.0	8.6	5.5
42	8.7	6.1	13.7	14.8	6.1	2.4	2.4	4.6	3.4	9.1	5.9
44	9.3	6.3	14.3	15.6	6.8	2.6	2.5	4.6	3.8	9.6	6.4
46	10.0	6.4	15.0	16.5	7.6	2.8	2.7	4.7	4.2	10.3	7.0
48	10.8	6.6	15.8	17.5	8.5	3.0	2.9	4.7	4.7	11.0	7.6
50	11.8	6.8	16.7	18.7	9.5	3.2	3.1	4.8	5.3	11.9	8.2
52	13.0	7.1	17.8	20.1	10.8	3.4	3.3	4.8	6.0	13.0	8.9
54	14.4	7.3	19.2	21.8	12.4	3.6	3.5	4.9	6.9	14.3	9.7
56	16.3	7.6	20.9	23.9	14.4	3.8	3.7	4.9	8.0	15.9	10.7
58	18.8	8.0	23.2	26.8	17.0	4.1	4.0	5.0	9.4	18.2	11.7
60	22.4	8.3	26.4	30.8	20.8	4.4	4.3	5.1	11.5	21.3	13.0
62	28.2	8.8	31.4	37.0	26.8	4.8	4.6	5.2	14.9	26.3	14.7
64	39.8	9.4	41.4	49.2	38.6	5.2	5.1	5.3	21.4	36.2	16.9
66	87.8	10.4	82.0	98.3	87.2	5.9	5.7	5.4	48.4	76.6	20.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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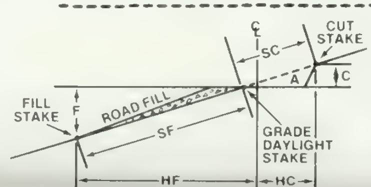
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

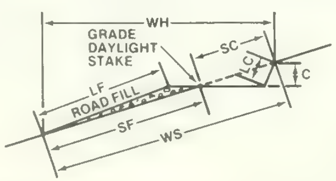
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 8 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.4	4.5	8.9	8.9	.8	.5	.4	4.2	.4	4.7	1.0
12	4.5	4.6	9.1	9.2	1.0	.6	.5	4.3	.5	4.8	1.2
14	4.7	4.7	9.3	9.4	1.2	.7	.7	4.3	.7	5.0	1.4
16	4.9	4.8	9.5	9.7	1.4	.8	.8	4.4	.8	5.2	1.6
18	5.0	4.9	9.8	9.9	1.6	1.0	.9	4.4	.9	5.3	1.9
20	5.2	5.0	10.0	10.2	1.8	1.1	1.0	4.5	1.0	5.5	2.2
22	5.4	5.1	10.3	10.5	2.1	1.2	1.1	4.5	1.2	5.8	2.4
24	5.7	5.2	10.6	10.9	2.4	1.4	1.2	4.6	1.3	6.0	2.7
26	5.9	5.4	10.9	11.3	2.7	1.5	1.3	4.7	1.5	6.2	3.0
28	6.2	5.5	11.2	11.7	3.0	1.7	1.5	4.7	1.7	6.5	3.4
30	6.5	5.6	11.6	12.1	3.3	1.8	1.6	4.8	1.9	6.8	3.7
32	6.8	5.8	12.0	12.6	3.7	2.0	1.8	4.9	2.1	7.1	4.1
34	7.2	6.0	12.4	13.1	4.1	2.1	1.9	5.0	2.3	7.5	4.5
36	7.6	6.1	12.9	13.7	4.6	2.3	2.1	5.0	2.6	7.8	4.9
38	8.0	6.3	13.4	14.3	5.1	2.5	2.2	5.1	2.8	8.3	5.4
40	8.5	6.5	13.9	15.0	5.7	2.7	2.4	5.2	3.2	8.7	5.9
42	9.1	6.7	14.6	15.8	6.3	2.9	2.6	5.3	3.5	9.3	6.4
44	9.7	7.0	15.3	16.7	7.1	3.1	2.8	5.4	3.9	9.9	7.0
46	10.5	7.2	16.1	17.7	7.9	3.4	3.0	5.5	4.4	10.6	7.6
48	11.4	7.5	17.0	18.9	8.9	3.6	3.2	5.6	4.9	11.4	8.3
50	12.4	7.8	18.1	20.2	10.0	3.9	3.5	5.7	5.6	12.3	9.1
52	13.7	8.1	19.4	21.8	11.4	4.2	3.7	5.9	6.3	13.5	10.0
54	15.3	8.5	20.9	23.8	13.1	4.5	4.0	6.0	7.3	14.9	10.9
56	17.4	8.9	22.9	26.2	15.3	4.8	4.3	6.2	8.5	16.7	12.1
58	20.1	9.3	25.5	29.5	18.2	5.2	4.7	6.3	10.1	19.1	13.4
60	24.1	9.9	29.1	34.0	22.4	5.7	5.1	6.5	12.4	22.6	15.1
62	30.5	10.5	34.9	41.1	29.0	6.2	5.6	6.8	16.1	28.1	17.2
64	43.4	11.4	46.2	54.8	42.2	6.9	6.2	7.1	23.4	39.1	20.1
66	97.0	12.9	91.7	109.9	96.4	7.9	7.1	7.5	53.5	84.2	25.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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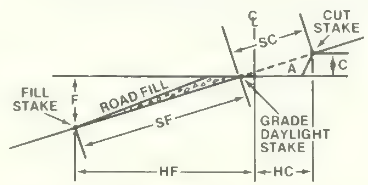
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

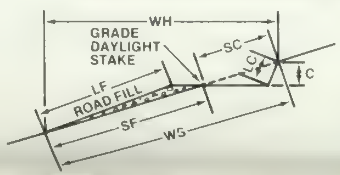
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 8 FEET

CUT SLOPE = .75 TO 1

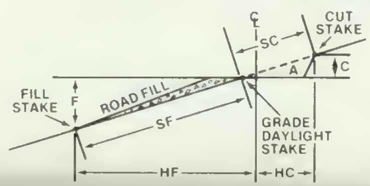
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.4	4.6	9.0	9.1	.8	.6	.5	4.3	.4	4.7	1.0
12	4.6	4.7	9.2	9.3	1.0	.7	.6	4.4	.5	4.8	1.2
14	4.7	4.8	9.5	9.6	1.2	.8	.7	4.5	.7	5.0	1.4
16	4.9	5.0	9.8	9.9	1.4	1.0	.8	4.6	.8	5.2	1.7
18	5.1	5.1	10.0	10.2	1.6	1.1	.9	4.7	.9	5.4	2.0
20	5.3	5.2	10.3	10.5	1.9	1.3	1.0	4.8	1.0	5.6	2.2
22	5.5	5.4	10.6	10.9	2.1	1.4	1.2	4.9	1.2	5.8	2.5
24	5.8	5.5	11.0	11.3	2.4	1.6	1.3	5.0	1.3	6.0	2.8
26	6.0	5.7	11.4	11.7	2.7	1.8	1.4	5.1	1.5	6.3	3.2
28	6.3	5.9	11.7	12.2	3.1	2.0	1.6	5.2	1.7	6.6	3.5
30	6.6	6.1	12.2	12.7	3.4	2.2	1.7	5.3	1.9	6.9	3.9
32	7.0	6.3	12.6	13.3	3.8	2.4	1.9	5.4	2.1	7.2	4.3
34	7.4	6.5	13.1	13.9	4.3	2.6	2.1	5.6	2.4	7.6	4.8
36	7.8	6.7	13.7	14.5	4.8	2.8	2.3	5.7	2.6	8.0	5.3
38	8.3	7.0	14.3	15.3	5.3	3.1	2.5	5.9	2.9	8.4	5.8
40	8.8	7.3	14.9	16.1	5.9	3.4	2.7	6.0	3.3	8.9	6.4
42	9.5	7.6	15.7	17.0	6.6	3.7	2.9	6.2	3.7	9.5	7.0
44	10.2	7.9	16.5	18.1	7.4	4.0	3.2	6.4	4.1	10.2	7.7
46	11.0	8.2	17.5	19.3	8.3	4.3	3.4	6.6	4.6	10.9	8.4
48	12.0	8.6	18.6	20.6	9.4	4.7	3.7	6.8	5.2	11.8	9.3
50	13.2	9.0	19.9	22.2	10.6	5.1	4.0	7.0	5.9	12.8	10.2
52	14.6	9.5	21.4	24.1	12.1	5.5	4.4	7.3	6.7	14.1	11.3
54	16.4	10.0	23.3	26.4	14.0	6.0	4.8	7.6	7.8	15.7	12.6
56	18.7	10.7	25.6	29.3	16.5	6.5	5.2	7.9	9.1	17.7	14.0
58	21.8	11.3	28.7	33.2	19.7	7.1	5.7	8.3	10.9	20.4	15.8
60	26.3	12.2	33.0	38.5	24.4	7.8	6.3	8.7	13.5	24.3	18.0
62	33.6	13.2	39.8	46.8	31.9	8.7	7.0	9.2	17.7	30.6	20.9
64	48.4	14.5	53.0	62.9	47.0	9.8	7.8	9.9	26.1	43.1	25.0
66	110.1	16.8	105.9	126.9	109.3	11.6	9.3	10.9	60.6	95.0	32.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

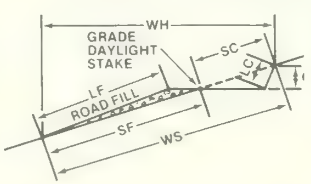
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 8 FEET

CUT SLOPE = 1.0 TO 1

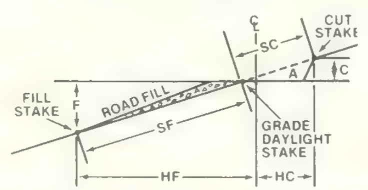
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.5	4.7	9.1	9.2	.8	.7	.5	4.5	.4	4.7	1.0
12	4.6	4.8	9.4	9.5	1.0	.8	.6	4.6	.6	4.8	1.2
14	4.8	5.0	9.7	9.8	1.2	1.0	.7	4.7	.7	5.0	1.5
16	5.0	5.1	10.0	10.1	1.4	1.1	.8	4.8	.8	5.2	1.7
18	5.2	5.3	10.3	10.5	1.7	1.3	.9	4.9	.9	5.4	2.0
20	5.4	5.5	10.7	10.9	1.9	1.5	1.1	5.1	1.1	5.6	2.3
22	5.6	5.7	11.0	11.3	2.2	1.7	1.2	5.2	1.2	5.8	2.6
24	5.9	5.9	11.4	11.8	2.5	1.9	1.4	5.4	1.4	6.1	3.0
26	6.2	6.1	11.9	12.3	2.8	2.2	1.5	5.5	1.6	6.3	3.3
28	6.5	6.3	12.3	12.8	3.2	2.4	1.7	5.7	1.7	6.6	3.7
30	6.8	6.6	12.8	13.4	3.5	2.7	1.9	5.9	2.0	6.9	4.2
32	7.2	6.8	13.4	14.0	4.0	2.9	2.1	6.1	2.2	7.3	4.6
34	7.6	7.1	14.0	14.8	4.4	3.2	2.3	6.3	2.5	7.7	5.1
36	8.1	7.5	14.6	15.6	5.0	3.6	2.5	6.5	2.7	8.1	5.7
38	8.6	7.8	15.4	16.5	5.5	3.9	2.8	6.8	3.1	8.6	6.3
40	9.3	8.2	16.2	17.4	6.2	4.3	3.0	7.0	3.4	9.2	6.9
42	9.9	8.6	17.1	18.6	6.9	4.7	3.3	7.3	3.9	9.8	7.7
44	10.7	9.1	18.2	19.8	7.8	5.2	3.7	7.7	4.3	10.5	8.5
46	11.7	9.6	19.3	21.3	8.8	5.7	4.0	8.0	4.9	11.3	9.4
48	12.8	10.2	20.7	23.0	10.0	6.2	4.4	8.4	5.5	12.3	10.5
50	14.1	10.8	22.3	24.9	11.4	6.8	4.8	8.8	6.3	13.5	11.7
52	15.8	11.6	24.2	27.3	13.1	7.5	5.3	9.3	7.3	14.9	13.1
54	17.8	12.4	26.6	30.2	15.3	8.3	5.9	9.9	8.5	16.7	14.8
56	20.5	13.4	29.6	33.9	18.0	9.3	6.5	10.5	10.0	19.0	16.8
58	24.1	14.6	33.5	38.7	21.8	10.3	7.3	11.3	12.1	22.2	19.3
60	29.4	16.0	38.9	45.4	27.3	11.6	8.2	12.2	15.1	26.7	22.5
62	38.1	17.7	47.5	55.9	36.2	13.2	9.4	13.4	20.1	34.1	26.8
64	55.8	20.2	64.0	76.0	54.2	15.4	10.9	14.9	30.1	49.1	33.3
66	130.9	24.3	129.5	155.2	130.0	19.0	13.4	17.4	72.1	112.1	46.3

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

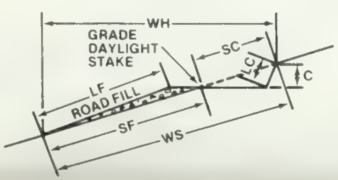
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 8 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.5	4.9	9.4	9.5	.8	.9	.5	4.7	.5	4.7	1.0
12	4.7	5.1	9.8	9.8	1.0	1.1	.6	4.9	.6	4.8	1.3
14	4.9	5.3	10.1	10.2	1.2	1.3	.7	5.1	.7	5.0	1.5
16	5.1	5.5	10.5	10.7	1.5	1.6	.9	5.3	.8	5.2	1.8
18	5.3	5.8	11.0	11.1	1.7	1.9	1.0	5.5	.9	5.4	2.1
20	5.6	6.1	11.4	11.7	2.0	2.1	1.2	5.8	1.1	5.6	2.5
22	5.9	6.4	11.9	12.2	2.3	2.5	1.4	6.1	1.3	5.9	2.8
24	6.2	6.7	12.5	12.9	2.6	2.8	1.6	6.3	1.4	6.2	3.2
26	6.5	7.1	13.1	13.6	2.9	3.2	1.8	6.7	1.6	6.5	3.7
28	6.9	7.5	13.8	14.3	3.3	3.6	2.0	7.0	1.9	6.8	4.2
30	7.3	7.9	14.5	15.2	3.8	4.1	2.3	7.4	2.1	7.1	4.7
32	7.7	8.4	15.4	16.2	4.3	4.6	2.6	7.8	2.4	7.5	5.3
34	8.3	9.0	16.3	17.2	4.8	5.2	2.9	8.3	2.7	8.0	6.0
36	8.9	9.6	17.4	18.5	5.4	5.9	3.3	8.9	3.0	8.5	6.8
38	9.5	10.4	18.6	19.9	6.1	6.6	3.7	9.5	3.4	9.1	7.7
40	10.3	11.2	20.0	21.5	6.9	7.5	4.2	10.2	3.8	9.8	8.7
42	11.2	12.2	21.6	23.5	7.9	8.5	4.7	11.1	4.4	10.5	9.8
44	12.3	13.4	23.5	25.7	9.0	9.7	5.4	12.1	5.0	11.4	11.2
46	13.6	14.8	25.8	28.4	10.3	11.1	6.2	13.3	5.7	12.5	12.9
48	15.2	16.5	28.6	31.7	11.9	12.9	7.1	14.7	6.6	13.9	14.9
50	17.2	18.6	32.0	35.8	13.8	15.0	8.3	16.5	7.7	15.5	17.3
52	19.7	21.3	36.4	41.0	16.4	17.7	9.8	18.8	9.1	17.6	20.5
54	23.0	24.9	42.1	47.9	19.7	21.3	11.8	21.7	10.9	20.4	24.6
56	27.5	29.8	50.0	57.3	24.2	26.3	14.6	25.9	13.4	24.1	30.3
58	34.1	37.0	61.5	71.1	30.9	33.5	18.6	31.9	17.1	29.7	38.6
60	44.8	48.5	80.0	93.3	41.5	45.0	25.0	41.5	23.0	38.5	52.0
62	64.5	70.0	114.3	134.5	61.3	66.5	36.9	59.3	34.0	55.0	76.7
64	113.9	123.5	200.0	237.5	110.7	120.1	66.6	103.9	61.4	96.1	138.6
66	459.8	498.7	800.0	958.5	456.6	495.3	274.7	416.1	253.3	383.9	571.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
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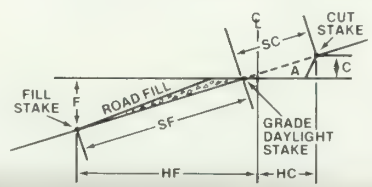
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

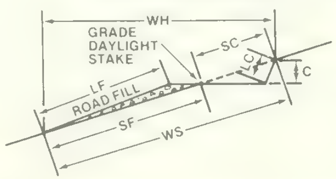
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 9 FEET

CUT SLOPE = VERTICAL

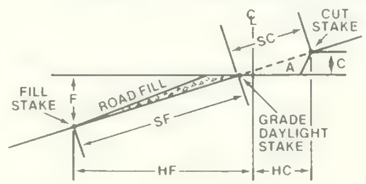
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.9	4.9	9.7	9.8	.9	.5	.5	4.5	.5	5.2	1.2
12	5.0	4.9	9.9	10.0	1.1	.6	.6	4.5	.6	5.4	1.4
14	5.2	5.0	10.1	10.2	1.3	.7	.7	4.5	.7	5.6	1.7
16	5.3	5.1	10.3	10.4	1.5	.8	.8	4.5	.8	5.8	2.0
18	5.5	5.1	10.5	10.6	1.8	.9	.9	4.5	1.0	6.0	2.3
20	5.7	5.2	10.7	10.9	2.0	1.0	1.0	4.5	1.1	6.2	2.6
22	5.9	5.3	10.9	11.2	2.3	1.1	1.1	4.5	1.3	6.4	2.9
24	6.1	5.3	11.1	11.5	2.6	1.2	1.2	4.5	1.4	6.6	3.2
26	6.4	5.4	11.4	11.8	2.9	1.4	1.4	4.5	1.6	6.9	3.6
28	6.6	5.5	11.7	12.1	3.2	1.5	1.5	4.5	1.8	7.2	3.9
30	6.9	5.6	12.0	12.5	3.6	1.6	1.6	4.5	2.0	7.5	4.3
32	7.3	5.7	12.3	12.9	4.0	1.7	1.7	4.5	2.2	7.8	4.7
34	7.6	5.8	12.7	13.4	4.4	1.9	1.9	4.5	2.4	8.2	5.1
36	8.0	5.9	13.1	13.9	4.9	2.0	2.0	4.5	2.7	8.6	5.5
38	8.4	6.0	13.5	14.4	5.4	2.1	2.1	4.5	3.0	9.0	6.0
40	8.9	6.1	14.0	15.0	6.0	2.3	2.3	4.5	3.3	9.5	6.5
42	9.5	6.3	14.5	15.7	6.6	2.4	2.4	4.5	3.7	10.0	7.0
44	10.1	6.4	15.1	16.5	7.3	2.6	2.6	4.5	4.1	10.6	7.5
46	10.8	6.5	15.8	17.4	8.2	2.7	2.7	4.5	4.5	11.3	8.1
48	11.7	6.7	16.6	18.4	9.1	2.9	2.9	4.5	5.1	12.1	8.8
50	12.7	6.9	17.5	19.6	10.2	3.1	3.1	4.5	5.7	13.0	9.5
52	13.9	7.1	18.6	21.0	11.6	3.3	3.3	4.5	6.4	14.1	10.3
54	15.4	7.3	20.0	22.7	13.2	3.5	3.5	4.5	7.3	15.5	11.1
56	17.4	7.5	21.7	24.9	15.3	3.7	3.7	4.5	8.5	17.2	12.1
58	20.0	7.8	24.0	27.8	18.1	3.9	3.9	4.5	10.0	19.5	13.2
60	23.7	8.1	27.3	31.8	22.0	4.2	4.2	4.5	12.2	22.8	14.6
62	29.7	8.5	32.4	38.2	28.2	4.5	4.5	4.5	15.6	27.9	16.2
64	41.6	9.0	42.6	50.6	40.4	4.9	4.9	4.5	22.4	38.1	18.5
66	91.0	9.9	84.2	100.9	90.4	5.4	5.4	4.5	50.1	79.7	22.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

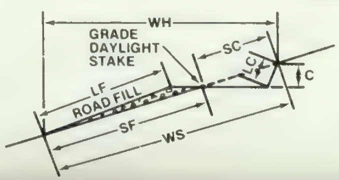
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 9 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.9	4.9	9.8	9.8	.9	.5	.5	4.5	.5	5.2	1.2
12	5.0	5.0	10.0	10.0	1.1	.6	.6	4.6	.6	5.4	1.5
14	5.2	5.0	10.2	10.3	1.3	.7	.7	4.6	.7	5.6	1.7
16	5.4	5.1	10.4	10.5	1.5	.8	.8	4.6	.8	5.8	2.0
18	5.5	5.2	10.6	10.7	1.8	.9	.9	4.6	1.0	6.0	2.3
20	5.7	5.3	10.8	11.0	2.0	1.0	1.0	4.6	1.1	6.2	2.6
22	6.0	5.3	11.0	11.3	2.3	1.2	1.1	4.6	1.3	6.4	2.9
24	6.2	5.4	11.3	11.6	2.6	1.3	1.3	4.6	1.4	6.7	3.3
26	6.4	5.5	11.6	12.0	2.9	1.4	1.4	4.6	1.6	6.9	3.6
28	6.7	5.6	11.9	12.3	3.3	1.5	1.5	4.7	1.8	7.2	4.0
30	7.0	5.7	12.2	12.7	3.6	1.7	1.6	4.7	2.0	7.5	4.4
32	7.3	5.8	12.5	13.2	4.0	1.8	1.8	4.7	2.2	7.9	4.8
34	7.7	5.9	12.9	13.6	4.5	1.9	1.9	4.7	2.5	8.2	5.2
36	8.1	6.1	13.3	14.2	4.9	2.1	2.1	4.7	2.7	8.6	5.6
38	8.5	6.2	13.8	14.7	5.5	2.2	2.2	4.7	3.0	9.0	6.1
40	9.0	6.3	14.3	15.4	6.1	2.4	2.4	4.7	3.4	9.5	6.6
42	9.6	6.5	14.8	16.1	6.7	2.5	2.5	4.8	3.7	10.1	7.2
44	10.3	6.6	15.5	16.9	7.4	2.7	2.7	4.8	4.1	10.7	7.8
46	11.0	6.8	16.2	17.8	8.3	2.9	2.8	4.8	4.6	11.4	8.4
48	11.9	7.0	17.0	18.9	9.3	3.0	3.0	4.8	5.1	12.2	9.1
50	12.9	7.2	18.0	20.1	10.4	3.2	3.2	4.8	5.8	13.2	9.8
52	14.2	7.4	19.2	21.6	11.8	3.4	3.4	4.8	6.5	14.3	10.7
54	15.7	7.7	20.6	23.4	13.5	3.7	3.6	4.9	7.5	15.7	11.6
56	17.7	7.9	22.4	25.7	15.6	3.9	3.9	4.9	8.7	17.5	12.6
58	20.4	8.2	24.8	28.6	18.5	4.1	4.1	4.9	10.2	19.9	13.8
60	24.3	8.6	28.2	32.8	22.5	4.4	4.4	4.9	12.5	23.2	15.3
62	30.4	9.0	33.5	39.5	28.9	4.8	4.8	5.0	16.0	28.6	17.1
64	42.8	9.6	44.1	52.4	41.6	5.2	5.2	5.0	23.1	39.1	19.5
66	93.9	10.5	87.2	104.5	93.3	5.8	5.8	5.1	51.7	82.1	23.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
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LF = LENGTH OF FILL SLOPE
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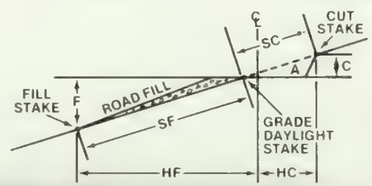
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

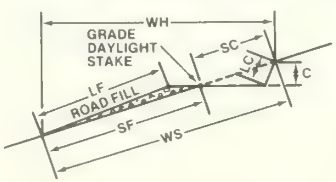
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 9 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	4.9	5.0	9.9	9.9	.9	.5	.5	4.6	.5	5.2	1.2
12	5.1	5.1	10.1	10.1	1.1	.6	.6	4.7	.6	5.4	1.5
14	5.2	5.1	10.3	10.4	1.3	.7	.7	4.7	.7	5.6	1.7
16	5.4	5.2	10.5	10.6	1.5	.8	.8	4.7	.9	5.8	2.0
18	5.6	5.3	10.7	10.9	1.8	1.0	.9	4.7	1.0	6.0	2.3
20	5.8	5.4	11.0	11.2	2.0	1.1	1.1	4.8	1.1	6.2	2.7
22	6.0	5.5	11.2	11.5	2.3	1.2	1.2	4.8	1.3	6.4	3.0
24	6.2	5.6	11.5	11.8	2.6	1.3	1.3	4.8	1.5	6.7	3.3
26	6.5	5.7	11.8	12.2	3.0	1.5	1.4	4.9	1.6	7.0	3.7
28	6.8	5.8	12.1	12.6	3.3	1.6	1.6	4.9	1.8	7.2	4.1
30	7.1	5.9	12.5	13.0	3.7	1.8	1.7	4.9	2.0	7.6	4.5
32	7.4	6.1	12.9	13.5	4.1	1.9	1.8	5.0	2.3	7.9	4.9
34	7.8	6.2	13.3	14.0	4.5	2.1	2.0	5.0	2.5	8.3	5.4
36	8.2	6.3	13.7	14.6	5.0	2.2	2.2	5.0	2.8	8.7	5.8
38	8.7	6.5	14.2	15.2	5.6	2.4	2.3	5.1	3.1	9.1	6.4
40	9.2	6.7	14.8	15.9	6.2	2.6	2.5	5.1	3.4	9.6	6.9
42	9.8	6.8	15.4	16.7	6.9	2.7	2.7	5.2	3.8	10.2	7.5
44	10.5	7.0	16.1	17.5	7.6	2.9	2.8	5.2	4.2	10.8	8.1
46	11.3	7.2	16.8	18.5	8.5	3.1	3.0	5.3	4.7	11.6	8.8
48	12.2	7.5	17.7	19.7	9.5	3.3	3.2	5.3	5.3	12.4	9.6
50	13.3	7.7	18.8	21.0	10.7	3.6	3.4	5.4	5.9	13.4	10.4
52	14.6	8.0	20.0	22.6	12.1	3.8	3.7	5.4	6.7	14.6	11.3
54	16.2	8.3	21.6	24.5	13.9	4.0	3.9	5.5	7.7	16.1	12.3
56	18.3	8.6	23.5	26.9	16.2	4.3	4.2	5.5	9.0	17.9	13.5
58	21.2	9.0	26.0	30.1	19.1	4.6	4.5	5.6	10.6	20.4	14.9
60	25.2	9.4	29.7	34.6	23.4	5.0	4.8	5.7	13.0	24.0	16.5
62	31.7	9.9	35.4	41.6	30.1	5.4	5.2	5.8	16.7	29.6	18.6
64	44.7	10.6	46.6	55.3	43.5	5.9	5.7	5.9	24.1	40.7	21.4
66	98.8	11.7	92.3	110.6	98.1	6.7	6.5	6.1	54.4	86.2	26.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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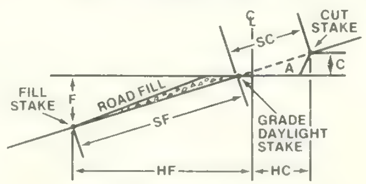
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

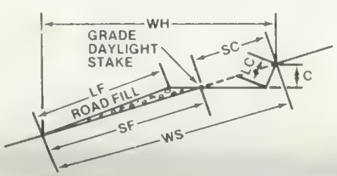
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 9 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	Δ
10	5.0	5.1	10.0	10.0	.9	.6	.5	4.8	.5	5.2	1.2
12	5.1	5.2	10.2	10.3	1.1	.7	.6	4.8	.6	5.4	1.5
14	5.3	5.3	10.5	10.6	1.3	.8	.7	4.9	.7	5.6	1.8
16	5.5	5.4	10.7	10.9	1.6	1.0	.9	4.9	.9	5.8	2.1
18	5.7	5.5	11.0	11.2	1.8	1.1	1.0	5.0	1.0	6.0	2.4
20	5.9	5.6	11.3	11.5	2.1	1.2	1.1	5.1	1.2	6.2	2.7
22	6.1	5.8	11.6	11.9	2.4	1.4	1.2	5.1	1.3	6.5	3.1
24	6.4	5.9	11.9	12.3	2.7	1.5	1.4	5.2	1.5	6.7	3.5
26	6.6	6.0	12.3	12.7	3.0	1.7	1.5	5.3	1.7	7.0	3.9
28	6.9	6.2	12.6	13.1	3.4	1.9	1.7	5.3	1.9	7.3	4.3
30	7.3	6.3	13.0	13.6	3.8	2.0	1.8	5.4	2.1	7.6	4.7
32	7.6	6.5	13.5	14.2	4.2	2.2	2.0	5.5	2.3	8.0	5.2
34	8.0	6.7	14.0	14.7	4.7	2.4	2.2	5.6	2.6	8.4	5.7
36	8.5	6.9	14.5	15.4	5.2	2.6	2.3	5.7	2.9	8.8	6.2
38	9.0	7.1	15.1	16.1	5.8	2.8	2.5	5.8	3.2	9.3	6.8
40	9.6	7.3	15.7	16.9	6.4	3.0	2.7	5.9	3.6	9.8	7.4
42	10.2	7.6	16.4	17.8	7.1	3.3	2.9	6.0	4.0	10.4	8.1
44	10.9	7.8	17.2	18.8	7.9	3.5	3.2	6.1	4.4	11.1	8.8
46	11.8	8.1	18.1	19.9	8.9	3.8	3.4	6.2	4.9	11.9	9.6
48	12.8	8.4	19.1	21.2	10.0	4.1	3.6	6.3	5.5	12.8	10.5
50	14.0	8.8	20.3	22.7	11.3	4.4	3.9	6.5	6.3	13.9	11.5
52	15.4	9.1	21.8	24.5	12.8	4.7	4.2	6.6	7.1	15.2	12.6
54	17.2	9.5	23.5	26.8	14.8	5.1	4.5	6.8	8.2	16.8	13.9
56	19.5	10.0	25.8	29.5	17.2	5.5	4.9	6.9	9.5	18.8	15.3
58	22.6	10.5	28.7	33.1	20.5	5.9	5.3	7.1	11.4	21.5	17.0
60	27.1	11.1	32.8	38.2	25.2	6.4	5.7	7.4	14.0	25.4	19.1
62	34.3	11.9	39.3	46.2	32.6	7.0	6.3	7.6	18.1	31.6	21.7
64	48.8	12.8	51.9	61.7	47.4	7.7	6.9	8.0	26.3	44.0	25.5
66	109.2	14.5	103.2	123.6	108.4	8.9	8.0	8.5	60.1	94.7	32.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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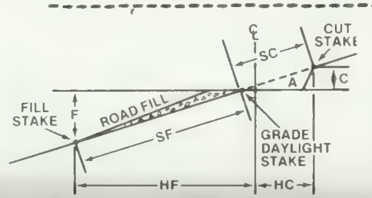
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

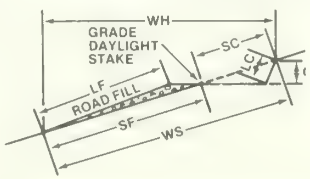
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 9 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.0	5.2	10.1	10.2	.9	.6	.5	4.9	.5	5.2	1.2
12	5.2	5.3	10.4	10.5	1.1	.8	.6	5.0	.6	5.4	1.5
14	5.3	5.4	10.7	10.8	1.3	.9	.8	5.1	.7	5.6	1.8
16	5.5	5.6	11.0	11.1	1.6	1.1	.9	5.2	.9	5.8	2.1
18	5.7	5.7	11.3	11.5	1.8	1.3	1.0	5.3	1.0	6.0	2.5
20	6.0	5.9	11.6	11.9	2.1	1.4	1.2	5.4	1.2	6.3	2.8
22	6.2	6.0	12.0	12.3	2.4	1.6	1.3	5.5	1.3	6.5	3.2
24	6.5	6.2	12.4	12.7	2.7	1.8	1.5	5.6	1.5	6.8	3.6
26	6.8	6.4	12.8	13.2	3.1	2.0	1.6	5.7	1.7	7.1	4.0
28	7.1	6.6	13.2	13.7	3.5	2.2	1.8	5.8	1.9	7.4	4.5
30	7.5	6.8	13.7	14.3	3.9	2.5	2.0	6.0	2.1	7.7	5.0
32	7.9	7.1	14.2	14.9	4.3	2.7	2.1	6.1	2.4	8.1	5.5
34	8.3	7.3	14.8	15.6	4.8	2.9	2.4	6.3	2.7	8.5	6.1
36	8.8	7.6	15.4	16.4	5.4	3.2	2.6	6.4	3.0	9.0	6.7
38	9.3	7.9	16.1	17.2	6.0	3.5	2.8	6.6	3.3	9.5	7.3
40	10.0	8.2	16.8	18.1	6.7	3.8	3.0	6.8	3.7	10.0	8.0
42	10.7	8.5	17.7	19.2	7.4	4.1	3.3	7.0	4.1	10.7	8.8
44	11.5	8.9	18.6	20.3	8.3	4.5	3.6	7.2	4.6	11.4	9.7
46	12.4	9.3	19.7	21.7	9.3	4.8	3.9	7.4	5.2	12.3	10.6
48	13.5	9.7	20.9	23.2	10.5	5.2	4.2	7.6	5.8	13.3	11.7
50	14.8	10.2	22.4	25.0	12.0	5.7	4.5	7.9	6.6	14.4	12.9
52	16.4	10.7	24.1	27.1	13.7	6.2	4.9	8.2	7.6	15.9	14.3
54	18.4	11.3	26.2	29.7	15.8	6.7	5.4	8.5	8.8	17.6	15.9
56	21.0	12.0	28.8	33.0	18.5	7.3	5.9	8.9	10.3	19.9	17.8
58	24.5	12.8	32.3	37.3	22.2	8.0	6.4	9.3	12.3	23.0	20.0
60	29.6	13.7	37.1	43.3	27.5	8.8	7.0	9.8	15.2	27.4	22.8
62	37.8	14.8	44.8	52.7	35.9	9.8	7.8	10.4	19.9	34.4	26.4
64	54.4	16.4	59.6	70.8	52.9	11.0	8.8	11.1	29.3	48.5	31.6
66	123.8	18.9	119.1	142.7	123.0	13.0	10.4	12.3	68.2	106.8	41.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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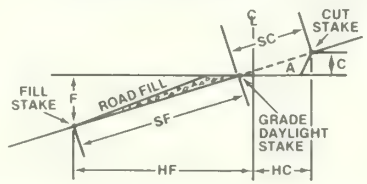
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

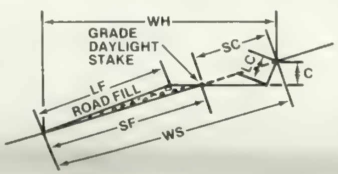
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 9 FEET

CUT SLOPE = 1.0 TO 1

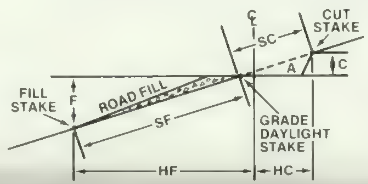
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.0	5.3	10.3	10.3	.9	.7	.5	5.0	.5	5.3	1.3
12	5.2	5.5	10.6	10.7	1.1	.9	.6	5.1	.6	5.4	1.5
14	5.4	5.6	10.9	11.0	1.3	1.1	.8	5.3	.7	5.6	1.9
16	5.6	5.8	11.2	11.4	1.6	1.3	.9	5.4	.9	5.8	2.2
18	5.8	6.0	11.6	11.8	1.9	1.5	1.1	5.6	1.0	6.0	2.5
20	6.1	6.2	12.0	12.2	2.1	1.7	1.2	5.7	1.2	6.3	2.9
22	6.3	6.4	12.4	12.7	2.5	1.9	1.4	5.9	1.4	6.5	3.3
24	6.6	6.6	12.9	13.2	2.8	2.2	1.5	6.0	1.5	6.8	3.8
26	6.9	6.8	13.3	13.8	3.2	2.4	1.7	6.2	1.7	7.1	4.2
28	7.3	7.1	13.9	14.4	3.5	2.7	1.9	6.4	2.0	7.5	4.7
30	7.7	7.4	14.4	15.1	4.0	3.0	2.1	6.6	2.2	7.8	5.3
32	8.1	7.7	15.1	15.8	4.5	3.3	2.3	6.8	2.5	8.2	5.8
34	8.6	8.0	15.7	16.6	5.0	3.7	2.6	7.1	2.8	8.6	6.5
36	9.1	8.4	16.5	17.5	5.6	4.0	2.8	7.3	3.1	9.1	7.2
38	9.7	8.8	17.3	18.5	6.2	4.4	3.1	7.6	3.5	9.7	7.9
40	10.4	9.2	18.2	19.6	7.0	4.8	3.4	7.9	3.9	10.3	8.8
42	11.2	9.7	19.3	20.9	7.8	5.3	3.8	8.3	4.3	11.0	9.7
44	12.1	10.2	20.4	22.3	8.8	5.8	4.1	8.6	4.9	11.8	10.8
46	13.1	10.8	21.8	23.9	9.9	6.4	4.5	9.0	5.5	12.7	12.0
48	14.4	11.5	23.3	25.8	11.2	7.0	5.0	9.5	6.2	13.8	13.3
50	15.9	12.2	25.1	28.1	12.8	7.7	5.4	9.9	7.1	15.2	14.8
52	17.7	13.0	27.3	30.7	14.7	8.5	6.0	10.5	8.2	16.8	16.6
54	20.0	14.0	29.9	34.0	17.2	9.4	6.6	11.1	9.5	18.8	18.7
56	23.0	15.1	33.2	38.1	20.3	10.4	7.4	11.9	11.3	21.4	21.3
58	27.1	16.4	37.6	43.5	24.5	11.6	8.2	12.7	13.6	24.9	24.4
60	33.1	18.0	43.8	51.1	30.7	13.1	9.2	13.7	17.0	30.1	28.5
62	42.9	20.0	53.4	62.9	40.7	14.9	10.5	15.0	22.6	38.4	33.9
64	62.8	22.7	72.0	85.5	61.0	17.3	12.2	16.7	33.9	55.3	42.1
66	147.2	27.4	145.7	174.6	146.2	21.3	15.1	19.6	81.1	126.1	58.6

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

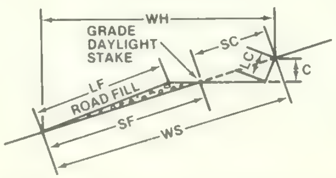
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 9 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.1	5.5	10.6	10.6	.9	1.0	.6	5.3	.5	5.3	1.3
12	5.3	5.8	11.0	11.1	1.1	1.2	.7	5.5	.6	5.4	1.6
14	5.5	6.0	11.4	11.5	1.4	1.5	.8	5.7	.8	5.6	1.9
16	5.8	6.2	11.8	12.0	1.6	1.8	1.0	6.0	.9	5.9	2.3
18	6.0	6.5	12.3	12.5	1.9	2.1	1.2	6.2	1.1	6.1	2.7
20	6.3	6.8	12.9	13.1	2.2	2.4	1.3	6.5	1.2	6.4	3.1
22	6.6	7.2	13.4	13.8	2.6	2.8	1.5	6.8	1.4	6.6	3.6
24	6.9	7.5	14.1	14.5	2.9	3.2	1.8	7.1	1.6	6.9	4.1
26	7.3	7.9	14.8	15.2	3.3	3.6	2.0	7.5	1.8	7.3	4.7
28	7.7	8.4	15.5	16.1	3.8	4.1	2.3	7.9	2.1	7.6	5.3
30	8.2	8.9	16.4	17.1	4.2	4.6	2.6	8.3	2.4	8.0	6.0
32	8.7	9.5	17.3	18.2	4.8	5.2	2.9	8.8	2.7	8.5	6.7
34	9.3	10.1	18.4	19.4	5.4	5.9	3.2	9.4	3.0	9.0	7.6
36	10.0	10.8	19.6	20.8	6.1	6.6	3.7	10.0	3.4	9.6	8.6
38	10.7	11.6	20.9	22.4	6.9	7.5	4.1	10.7	3.8	10.2	9.7
40	11.6	12.6	22.5	24.2	7.8	8.4	4.7	11.5	4.3	11.0	11.0
42	12.7	13.7	24.3	26.4	8.8	9.6	5.3	12.5	4.9	11.9	12.4
44	13.9	15.0	26.5	28.9	10.1	10.9	6.1	13.6	5.6	12.9	14.2
46	15.3	16.6	29.0	32.0	11.5	12.5	6.9	14.9	6.4	14.1	16.3
48	17.1	18.6	32.1	35.7	13.3	14.5	8.0	16.5	7.4	15.6	18.8
50	19.3	20.9	36.0	40.2	15.6	16.9	9.4	18.5	8.6	17.5	21.9
52	22.1	24.0	40.9	46.1	19.4	20.0	11.1	21.1	10.2	19.8	25.9
54	25.8	28.0	47.4	53.8	22.1	24.0	13.3	24.5	12.3	22.9	31.2
56	30.9	33.5	56.2	64.5	27.2	29.5	16.4	29.1	15.1	27.2	38.4
58	38.4	41.6	69.2	80.0	34.7	37.7	20.9	35.8	19.3	33.4	48.9
60	50.3	54.6	90.0	105.0	46.7	50.7	28.1	46.6	25.9	43.4	65.8
62	72.6	78.7	128.6	151.3	68.9	74.8	41.5	66.7	38.2	61.9	97.1
64	128.1	139.0	225.0	267.1	124.5	135.1	74.9	116.9	69.1	108.1	175.4
66	517.3	561.1	900.0	1078.3	513.7	557.2	309.1	468.1	284.9	431.9	723.6

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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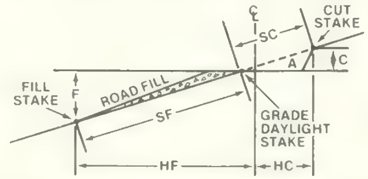
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

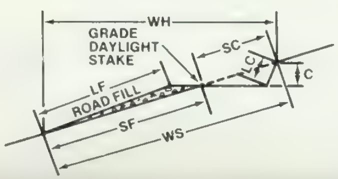
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 10 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.4	5.4	10.8	10.9	1.0	.5	.5	5.0	.5	5.8	1.5
12	5.6	5.5	11.0	11.1	1.2	.7	.7	5.0	.7	6.0	1.8
14	5.8	5.5	11.2	11.3	1.4	.8	.8	5.0	.8	6.2	2.1
16	5.9	5.6	11.4	11.6	1.7	.9	.9	5.0	.9	6.4	2.5
18	6.1	5.7	11.6	11.8	2.0	1.0	1.0	5.0	1.1	6.6	2.8
20	6.3	5.8	11.9	12.1	2.2	1.1	1.1	5.0	1.2	6.9	3.2
22	6.6	5.8	12.1	12.4	2.5	1.3	1.3	5.0	1.4	7.1	3.6
24	6.8	5.9	12.4	12.7	2.9	1.4	1.4	5.0	1.6	7.4	4.0
26	7.1	6.0	12.7	13.1	3.2	1.5	1.5	5.0	1.8	7.7	4.4
28	7.4	6.1	13.0	13.5	3.6	1.6	1.6	5.0	2.0	8.0	4.8
30	7.7	6.2	13.3	13.9	4.0	1.8	1.8	5.0	2.2	8.3	5.3
32	8.1	6.3	13.7	14.4	4.4	1.9	1.9	5.0	2.5	8.7	5.8
34	8.5	6.4	14.1	14.9	4.9	2.1	2.1	5.0	2.7	9.1	6.3
36	8.9	6.5	14.5	15.4	5.4	2.2	2.2	5.0	3.0	9.5	6.8
38	9.4	6.7	15.0	16.0	6.0	2.4	2.4	5.0	3.3	10.0	7.4
40	9.9	6.8	15.5	16.7	6.6	2.5	2.5	5.0	3.7	10.5	8.0
42	10.5	6.9	16.1	17.5	7.4	2.7	2.7	5.0	4.1	11.1	8.6
44	11.2	7.1	16.8	18.3	8.2	2.9	2.9	5.0	4.5	11.8	9.3
46	12.0	7.3	17.5	19.3	9.1	3.0	3.0	5.0	5.0	12.5	10.0
48	13.0	7.5	18.4	20.4	10.1	3.2	3.2	5.0	5.6	13.4	10.8
50	14.1	7.7	19.5	21.8	11.4	3.4	3.4	5.0	6.3	14.5	11.7
52	15.5	7.9	20.7	23.3	12.9	3.6	3.6	5.0	7.1	15.7	12.7
54	17.1	8.1	22.2	25.3	14.7	3.9	3.9	5.0	8.1	17.2	13.7
56	19.3	8.4	24.1	27.7	17.0	4.1	4.1	5.0	9.4	19.1	14.9
58	22.2	8.7	26.7	30.9	20.1	4.4	4.4	5.0	11.1	21.7	16.3
60	26.3	9.0	30.3	35.4	24.4	4.6	4.6	5.0	13.5	25.3	18.0
62	33.0	9.5	36.1	42.4	31.3	5.0	5.0	5.0	17.4	31.1	20.0
64	46.2	10.0	47.4	56.2	44.9	5.4	5.4	5.0	24.9	42.4	22.8
66	101.1	11.0	93.6	112.1	100.4	6.0	6.0	5.0	55.7	88.6	27.7

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
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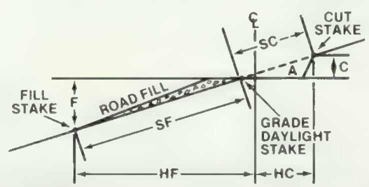
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

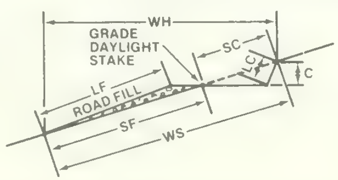
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 10 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.4	5.5	10.9	10.9	1.0	.5	.5	5.1	.5	5.8	1.5
12	5.6	5.5	11.1	11.1	1.2	.7	.7	5.1	.7	6.0	1.8
14	5.8	5.6	11.3	11.4	1.4	.8	.8	5.1	.8	6.2	2.1
16	6.0	5.7	11.5	11.6	1.7	.9	.9	5.1	.9	6.4	2.5
18	6.2	5.8	11.7	11.9	2.0	1.0	1.0	5.1	1.1	6.6	2.8
20	6.4	5.8	12.0	12.2	2.3	1.2	1.1	5.1	1.3	6.9	3.2
22	6.6	5.9	12.3	12.6	2.6	1.3	1.3	5.1	1.4	7.1	3.6
24	6.9	6.0	12.5	12.9	2.9	1.4	1.4	5.1	1.6	7.4	4.0
26	7.1	6.1	12.9	13.3	3.2	1.6	1.5	5.2	1.8	7.7	4.5
28	7.4	6.2	13.2	13.7	3.6	1.7	1.7	5.2	2.0	8.0	4.9
30	7.8	6.4	13.5	14.1	4.0	1.8	1.8	5.2	2.2	8.4	5.4
32	8.1	6.5	13.9	14.6	4.5	2.0	2.0	5.2	2.5	8.7	5.9
34	8.5	6.6	14.3	15.1	5.0	2.1	2.1	5.2	2.8	9.1	6.4
36	9.0	6.7	14.8	15.7	5.5	2.3	2.3	5.2	3.0	9.6	7.0
38	9.5	6.9	15.3	16.4	6.1	2.5	2.4	5.2	3.4	10.1	7.6
40	10.0	7.0	15.9	17.1	6.7	2.6	2.6	5.3	3.7	10.6	8.2
42	10.7	7.2	16.5	17.9	7.5	2.8	2.8	5.3	4.1	11.2	8.9
44	11.4	7.4	17.2	18.8	8.3	3.0	3.0	5.3	4.6	11.9	9.6
46	12.2	7.6	18.0	19.8	9.2	3.2	3.2	5.3	5.1	12.7	10.4
48	13.2	7.8	18.9	21.0	10.3	3.4	3.4	5.3	5.7	13.6	11.2
50	14.4	8.0	20.0	22.3	11.6	3.6	3.6	5.4	6.4	14.6	12.1
52	15.8	8.2	21.3	24.0	13.1	3.8	3.8	5.4	7.3	15.9	13.2
54	17.5	8.5	22.9	26.0	15.0	4.1	4.0	5.4	8.3	17.5	14.3
56	19.7	8.8	24.9	28.5	17.4	4.3	4.3	5.4	9.6	19.4	15.6
58	22.7	9.1	27.5	31.8	20.5	4.6	4.6	5.5	11.4	22.1	17.1
60	27.0	9.5	31.3	36.5	25.0	4.9	4.9	5.5	13.9	25.8	18.9
62	33.8	10.0	37.3	43.8	32.1	5.3	5.3	5.5	17.8	31.7	21.1
64	47.5	10.7	49.0	58.2	46.2	5.8	5.7	5.6	25.6	43.4	24.1
66	104.3	11.7	96.9	116.1	103.6	6.5	6.5	5.6	57.5	91.2	29.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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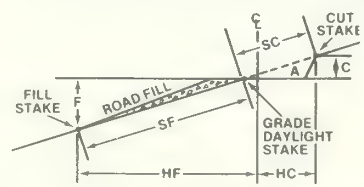
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

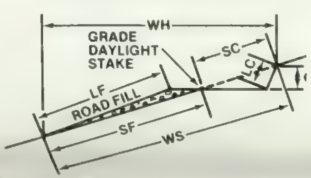
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 10 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.5	5.5	11.0	11.0	1.0	.6	.6	5.1	.5	5.8	1.5
12	5.6	5.6	11.2	11.3	1.2	.7	.7	5.2	.7	6.0	1.8
14	5.8	5.7	11.4	11.5	1.5	.8	.8	5.2	.8	6.2	2.2
16	6.0	5.8	11.7	11.8	1.7	.9	.9	5.2	.9	6.4	2.5
18	6.2	5.9	11.9	12.1	2.0	1.1	1.0	5.3	1.1	6.7	2.9
20	6.4	6.0	12.2	12.4	2.3	1.2	1.2	5.3	1.3	6.9	3.3
22	6.7	6.1	12.5	12.8	2.6	1.4	1.3	5.3	1.4	7.2	3.7
24	6.9	6.2	12.8	13.2	2.9	1.5	1.5	5.4	1.6	7.4	4.1
26	7.2	6.3	13.1	13.6	3.3	1.6	1.6	5.4	1.8	7.7	4.6
28	7.5	6.5	13.5	14.0	3.7	1.8	1.7	5.4	2.0	8.1	5.0
30	7.9	6.6	13.9	14.5	4.1	2.0	1.9	5.5	2.3	8.4	5.5
32	8.3	6.7	14.3	15.0	4.5	2.1	2.1	5.5	2.5	8.8	6.1
34	8.7	6.9	14.7	15.6	5.0	2.3	2.2	5.6	2.8	9.2	6.6
36	9.1	7.1	15.2	16.2	5.6	2.5	2.4	5.6	3.1	9.6	7.2
38	9.7	7.2	15.8	16.9	6.2	2.6	2.6	5.6	3.4	10.2	7.8
40	10.2	7.4	16.4	17.7	6.9	2.8	2.8	5.7	3.8	10.7	8.5
42	10.9	7.6	17.1	18.5	7.6	3.0	2.9	5.7	4.2	11.3	9.2
44	11.7	7.8	17.8	19.5	8.5	3.2	3.1	5.8	4.7	12.0	10.0
46	12.5	8.0	18.7	20.6	9.4	3.5	3.4	5.8	5.2	12.9	10.9
48	13.6	8.3	19.7	21.8	10.6	3.7	3.6	5.9	5.9	13.8	11.8
50	14.8	8.6	20.9	23.3	11.9	3.9	3.8	6.0	6.6	14.9	12.8
52	16.2	8.9	22.3	25.1	13.5	4.2	4.1	6.0	7.5	16.2	14.0
54	18.0	9.2	24.0	27.2	15.5	4.5	4.4	6.1	8.6	17.9	15.2
56	20.4	9.5	26.1	29.9	18.0	4.8	4.7	6.2	10.0	19.9	16.7
58	23.5	9.9	28.9	33.5	21.3	5.1	5.0	6.2	11.8	22.7	18.4
60	28.0	10.4	33.0	38.4	26.0	5.5	5.4	6.3	14.4	26.6	20.4
62	35.2	11.0	39.3	46.3	33.5	6.0	5.8	6.4	18.6	32.9	22.9
64	49.7	11.8	51.8	61.5	48.3	6.5	6.3	6.6	26.8	45.2	26.4
66	109.8	13.0	102.5	122.8	109.0	7.4	7.2	6.8	60.5	95.7	32.6

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
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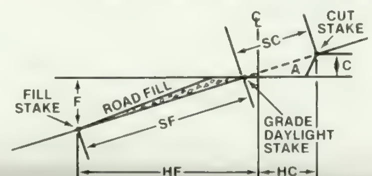
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

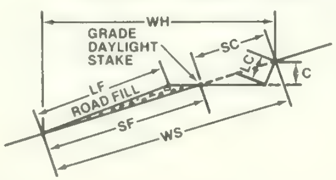
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 10 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.5	5.7	11.1	11.2	1.0	.6	.6	5.3	.5	5.8	1.5
12	5.7	5.8	11.4	11.4	1.2	.8	.7	5.3	.7	6.0	1.8
14	5.9	5.9	11.6	11.7	1.5	.9	.8	5.4	.8	6.2	2.2
16	6.1	6.0	11.9	12.1	1.7	1.1	.9	5.5	1.0	6.4	2.6
18	6.3	6.1	12.2	12.4	2.0	1.2	1.1	5.5	1.1	6.7	3.0
20	6.5	6.2	12.5	12.8	2.3	1.4	1.2	5.6	1.3	6.9	3.4
22	6.8	6.4	12.9	13.2	2.6	1.5	1.4	5.7	1.5	7.2	3.8
24	7.1	6.5	13.2	13.6	3.0	1.7	1.5	5.8	1.7	7.5	4.3
26	7.4	6.7	13.6	14.1	3.3	1.9	1.7	5.8	1.9	7.8	4.8
28	7.7	6.9	14.0	14.6	3.8	2.1	1.9	5.9	2.1	8.1	5.3
30	8.1	7.1	14.5	15.1	4.2	2.3	2.0	6.0	2.3	8.5	5.8
32	8.5	7.2	15.0	15.7	4.7	2.5	2.2	6.1	2.6	8.9	6.4
34	8.9	7.4	15.5	16.4	5.2	2.7	2.4	6.2	2.9	9.3	7.0
36	9.4	7.7	16.1	17.1	5.8	2.9	2.6	6.3	3.2	9.8	7.7
38	10.0	7.9	16.7	17.9	6.4	3.1	2.8	6.4	3.6	10.3	8.4
40	10.6	8.1	17.4	18.8	7.1	3.4	3.0	6.5	3.9	10.9	9.2
42	11.3	8.4	18.2	19.8	7.9	3.6	3.3	6.6	4.4	11.6	10.0
44	12.2	8.7	19.1	20.9	8.8	3.9	3.5	6.8	4.9	12.3	10.9
46	13.1	9.0	20.1	22.1	9.9	4.2	3.8	6.9	5.5	13.2	11.9
48	14.2	9.4	21.3	23.6	11.1	4.5	4.0	7.0	6.2	14.2	13.0
50	15.5	9.7	22.6	25.3	12.5	4.9	4.4	7.2	6.9	15.4	14.2
52	17.1	10.1	24.2	27.3	14.3	5.2	4.7	7.3	7.9	16.9	15.6
54	19.1	10.6	26.2	29.7	16.4	5.6	5.0	7.5	9.1	18.6	17.1
56	21.7	11.1	28.6	32.8	19.1	6.1	5.4	7.7	10.6	20.9	18.9
58	25.2	11.7	31.9	36.8	22.8	6.5	5.9	7.9	12.6	23.9	21.0
60	30.1	12.4	36.4	42.5	28.0	7.1	6.4	8.2	15.5	28.3	23.6
62	38.2	13.2	43.6	51.3	36.2	7.8	6.9	8.5	20.1	35.2	26.8
64	54.2	14.3	57.7	68.5	52.7	8.6	7.7	8.8	29.2	48.9	31.4
66	121.3	16.1	114.6	137.4	120.4	9.9	8.9	9.4	66.8	105.2	39.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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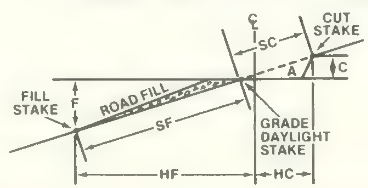
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

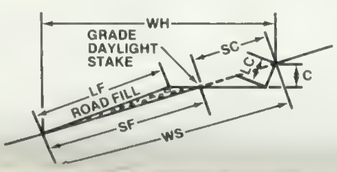
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 10 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.5	5.8	11.3	11.3	1.0	.7	.6	5.4	.6	5.8	1.5
12	5.7	5.9	11.6	11.6	1.2	.9	.7	5.5	.7	6.0	1.9
14	5.9	6.0	11.9	12.0	1.5	1.0	.8	5.6	.8	6.2	2.2
16	6.1	6.2	12.2	12.3	1.8	1.2	1.0	5.7	1.0	6.5	2.6
18	6.4	6.4	12.5	12.7	2.0	1.4	1.1	5.8	1.1	6.7	3.1
20	6.6	6.5	12.9	13.2	2.3	1.6	1.3	6.0	1.3	7.0	3.5
22	6.9	6.7	13.3	13.6	2.7	1.8	1.4	6.1	1.5	7.2	4.0
24	7.2	6.9	13.7	14.1	3.0	2.0	1.6	6.2	1.7	7.5	4.4
26	7.5	7.1	14.2	14.7	3.4	2.2	1.8	6.3	1.9	7.8	5.0
28	7.9	7.3	14.7	15.2	3.8	2.5	2.0	6.5	2.1	8.2	5.5
30	8.3	7.6	15.2	15.9	4.3	2.7	2.2	6.6	2.4	8.6	6.1
32	8.7	7.8	15.8	16.6	4.8	3.0	2.4	6.8	2.7	9.0	6.8
34	9.2	8.1	16.4	17.3	5.4	3.3	2.6	7.0	3.0	9.5	7.5
36	9.8	8.4	17.1	18.2	6.0	3.6	2.8	7.1	3.3	10.0	8.2
38	10.4	8.7	17.9	19.1	6.6	3.9	3.1	7.3	3.7	10.5	9.0
40	11.1	9.1	18.7	20.1	7.4	4.2	3.4	7.5	4.1	11.2	9.9
42	11.8	9.4	19.6	21.3	8.3	4.6	3.7	7.7	4.6	11.9	10.9
44	12.7	9.8	20.7	22.6	9.2	5.0	4.0	8.0	5.1	12.7	12.0
46	13.8	10.3	21.9	24.1	10.4	5.4	4.3	8.2	5.8	13.6	13.1
48	15.0	10.8	23.2	25.8	11.7	5.8	4.7	8.5	6.5	14.7	14.5
50	16.5	11.3	24.8	27.8	13.3	6.3	5.1	8.8	7.4	16.0	16.0
52	18.3	11.9	26.7	30.2	15.2	6.9	5.5	9.1	8.4	17.6	17.7
54	20.5	12.6	29.1	33.0	17.6	7.5	6.0	9.5	9.7	19.6	19.6
56	23.4	13.3	32.0	36.7	20.6	8.1	6.5	9.9	11.4	22.1	21.9
58	27.3	14.2	35.9	41.5	24.7	8.9	7.1	10.3	13.7	25.5	24.7
60	32.9	15.2	41.3	48.1	30.5	9.8	7.8	10.9	16.9	30.4	28.1
62	42.0	16.5	49.7	58.5	39.9	10.9	8.7	11.5	22.2	38.2	32.6
64	60.4	18.2	66.2	78.6	58.7	12.3	9.8	12.4	32.6	53.9	39.0
66	137.6	21.0	132.4	158.6	136.6	14.5	11.6	13.7	75.8	118.7	51.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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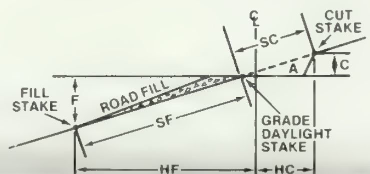
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

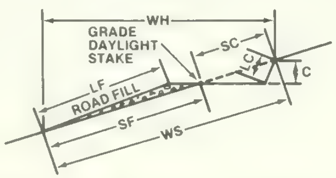
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 10 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.6	5.9	11.4	11.5	1.0	.8	.6	5.6	.6	5.8	1.5
12	5.8	6.1	11.8	11.8	1.2	1.0	.7	5.7	.7	6.0	1.9
14	6.0	6.2	12.1	12.2	1.5	1.2	.9	5.9	.8	6.2	2.3
16	6.2	6.4	12.5	12.6	1.8	1.4	1.0	6.0	1.0	6.5	2.7
18	6.5	6.6	12.9	13.1	2.1	1.7	1.2	6.2	1.1	6.7	3.1
20	6.7	6.8	13.3	13.6	2.4	1.9	1.3	6.3	1.3	7.0	3.6
22	7.0	7.1	13.8	14.1	2.7	2.2	1.5	6.5	1.5	7.3	4.1
24	7.4	7.3	14.3	14.7	3.1	2.4	1.7	6.7	1.7	7.6	4.6
26	7.7	7.6	14.8	15.3	3.5	2.7	1.9	6.9	1.9	7.9	5.2
28	8.1	7.9	15.4	16.0	3.9	3.0	2.1	7.1	2.2	8.3	5.8
30	8.5	8.2	16.0	16.7	4.4	3.3	2.4	7.4	2.5	8.7	6.5
32	9.0	8.5	16.7	17.6	5.0	3.7	2.6	7.6	2.7	9.1	7.2
34	9.5	8.9	17.5	18.5	5.5	4.1	2.9	7.9	3.1	9.6	8.0
36	10.1	9.3	18.3	19.5	6.2	4.5	3.2	8.2	3.4	10.2	8.9
38	10.8	9.8	19.2	20.6	6.9	4.9	3.5	8.5	3.8	10.8	9.8
40	11.6	10.2	20.2	21.8	7.7	5.4	3.8	8.8	4.3	11.4	10.8
42	12.4	10.8	21.4	23.2	8.7	5.9	4.2	9.2	4.8	12.2	12.0
44	13.4	11.4	22.7	24.8	9.8	6.5	4.6	9.6	5.4	13.1	13.3
46	14.6	12.0	24.2	26.6	11.0	7.1	5.0	10.0	6.1	14.2	14.8
48	16.0	12.7	25.9	28.7	12.5	7.8	5.5	10.5	6.9	15.4	16.4
50	17.6	13.5	27.9	31.2	14.2	8.6	6.1	11.1	7.9	16.8	19.3
52	19.7	14.5	30.3	34.1	16.4	9.4	6.7	11.7	9.1	18.6	20.5
54	22.3	15.5	33.2	37.8	19.1	10.4	7.4	12.4	10.6	20.9	23.1
56	25.6	16.7	36.9	42.3	22.5	11.6	8.2	13.2	12.5	23.8	26.3
58	30.1	18.2	41.8	48.3	27.3	12.9	9.1	14.1	15.1	27.7	30.2
60	36.8	20.0	48.7	56.8	34.1	14.5	10.3	15.3	18.9	33.4	35.1
62	47.7	22.2	59.4	69.8	45.3	16.5	11.7	16.7	25.1	42.7	41.9
64	69.8	25.2	80.0	95.0	67.8	19.2	13.6	18.6	37.6	61.4	52.0
66	163.6	30.4	161.9	194.0	162.4	23.7	16.8	21.8	90.1	140.2	72.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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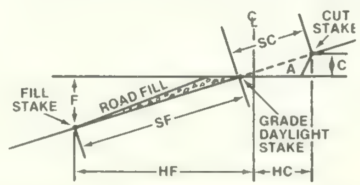
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

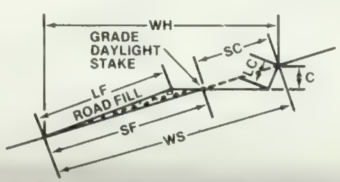
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 10 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	5.7	6.2	11.8	11.8	1.0	1.1	.6	5.9	.6	5.8	1.6
12	5.9	6.4	12.2	12.3	1.3	1.4	.8	6.1	.7	6.1	2.0
14	6.1	6.7	12.7	12.8	1.5	1.7	.9	6.4	.9	6.3	2.4
16	6.4	6.9	13.2	13.3	1.8	2.0	1.1	6.6	1.0	6.5	2.8
18	6.7	7.2	13.7	13.9	2.1	2.3	1.3	6.9	1.2	6.8	3.3
20	7.0	7.6	14.3	14.6	2.5	2.7	1.5	7.2	1.4	7.1	3.9
22	7.3	8.0	14.9	15.3	2.8	3.1	1.7	7.6	1.6	7.4	4.4
24	7.7	8.4	15.6	16.1	3.2	3.5	2.0	7.9	1.8	7.7	5.1
26	8.1	8.8	16.4	16.9	3.7	4.0	2.2	8.3	2.0	8.1	5.8
28	8.6	9.3	17.2	17.9	4.2	4.5	2.5	8.8	2.3	8.5	6.5
30	9.1	9.9	18.2	19.0	4.7	5.1	2.8	9.3	2.6	8.9	7.4
32	9.7	10.5	19.2	20.2	5.3	5.8	3.2	9.8	3.0	9.4	8.3
34	10.3	11.2	20.4	21.6	6.0	6.5	3.6	10.4	3.3	10.0	9.4
36	11.1	12.0	21.7	23.1	6.8	7.3	4.1	11.1	3.8	10.6	10.6
38	11.9	12.9	23.3	24.9	7.6	8.3	4.6	11.9	4.2	11.4	12.0
40	12.9	14.0	25.0	26.9	8.6	9.4	5.2	12.8	4.8	12.2	13.5
42	14.1	15.3	27.0	29.3	9.8	10.6	5.9	13.9	5.4	13.2	15.4
44	15.4	16.7	29.4	32.1	11.2	12.1	6.7	15.1	6.2	14.3	17.5
46	17.0	18.5	32.3	35.5	12.8	13.9	7.7	16.6	7.1	15.7	20.1
48	19.0	20.6	35.7	39.6	14.8	16.1	8.9	18.4	8.2	17.3	23.2
50	21.5	23.3	40.0	44.7	17.3	18.8	10.4	20.6	9.6	19.4	27.1
52	24.6	26.7	45.5	51.2	20.4	22.2	12.3	23.4	11.3	22.0	32.0
54	28.7	31.1	52.6	59.8	24.6	26.7	14.8	27.2	13.6	25.5	38.5
56	34.4	37.3	62.5	71.6	30.3	32.8	18.2	32.3	16.8	30.2	47.4
58	42.7	46.3	76.9	88.9	38.6	41.8	23.2	39.8	21.4	37.1	60.4
60	55.9	60.7	100.0	116.6	51.9	56.3	31.2	51.8	28.8	48.2	81.2
62	80.6	87.5	142.9	168.1	76.6	83.1	46.1	74.1	42.5	68.7	119.9
64	142.4	154.4	250.0	296.8	138.4	150.1	83.2	129.9	76.8	120.1	216.6
66	574.8	623.4	1000.0	1198.2	570.8	619.1	343.4	520.1	316.6	479.9	893.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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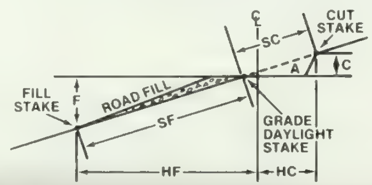
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

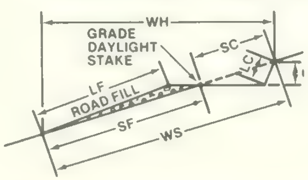
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 11 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.0	6.0	11.9	12.0	1.1	.6	.6	5.5	.6	6.4	1.8
12	6.1	6.0	12.1	12.2	1.3	.7	.7	5.5	.7	6.6	2.2
14	6.3	6.1	12.3	12.4	1.6	.8	.8	5.5	.9	6.8	2.6
16	6.5	6.2	12.5	12.7	1.9	1.0	1.0	5.5	1.0	7.0	3.0
18	6.7	6.3	12.8	13.0	2.2	1.1	1.1	5.5	1.2	7.3	3.4
20	7.0	6.3	13.1	13.3	2.5	1.2	1.2	5.5	1.4	7.6	3.9
22	7.2	6.4	13.3	13.6	2.8	1.4	1.4	5.5	1.6	7.8	4.3
24	7.5	6.5	13.6	14.0	3.2	1.5	1.5	5.5	1.8	8.1	4.8
26	7.8	6.6	13.9	14.4	3.5	1.7	1.7	5.5	2.0	8.4	5.3
28	8.1	6.7	14.3	14.8	3.9	1.8	1.8	5.5	2.2	8.8	5.8
30	8.5	6.8	14.7	15.3	4.4	2.0	2.0	5.5	2.4	9.2	6.4
32	8.9	6.9	15.1	15.8	4.9	2.1	2.1	5.5	2.7	9.6	7.0
34	9.3	7.1	15.5	16.4	5.4	2.3	2.3	5.5	3.0	10.0	7.6
36	9.8	7.2	16.0	17.0	6.0	2.4	2.4	5.5	3.3	10.5	8.2
38	10.3	7.3	16.5	17.6	6.6	2.6	2.6	5.5	3.7	11.0	8.9
40	10.9	7.5	17.1	18.4	7.3	2.8	2.8	5.5	4.1	11.6	9.7
42	11.6	7.6	17.7	19.2	8.1	3.0	3.0	5.5	4.5	12.2	10.4
44	12.4	7.8	18.5	20.2	9.0	3.1	3.1	5.5	5.0	13.0	11.3
46	13.2	8.0	19.3	21.2	10.0	3.3	3.3	5.5	5.5	13.8	12.2
48	14.3	8.2	20.3	22.5	11.1	3.5	3.5	5.5	6.2	14.8	13.1
50	15.5	8.4	21.4	23.9	12.5	3.8	3.8	5.5	6.9	15.9	14.2
52	17.0	8.7	22.8	25.7	14.2	4.0	4.0	5.5	7.8	17.3	15.3
54	18.9	8.9	24.4	27.8	16.2	4.2	4.2	5.5	9.0	18.9	16.6
56	21.2	9.2	26.6	30.4	18.7	4.5	4.5	5.5	10.4	21.1	18.1
58	24.4	9.5	29.4	33.9	22.1	4.8	4.8	5.5	12.2	23.9	19.8
60	29.0	9.9	33.3	38.9	26.9	5.1	5.1	5.5	14.9	27.8	21.8
62	36.3	10.4	39.7	46.7	34.4	5.5	5.5	5.5	19.1	34.2	24.2
64	50.8	11.0	52.1	61.9	49.4	5.9	5.9	5.5	27.4	46.6	27.6
66	111.3	12.1	102.9	123.3	110.5	6.6	6.6	5.5	61.3	97.4	33.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
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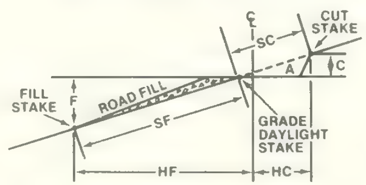
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

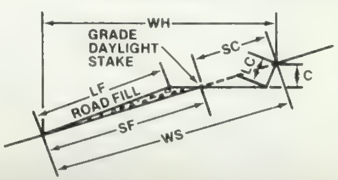
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 11 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.0	6.0	12.0	12.0	1.1	.6	.6	5.6	.6	6.4	1.8
12	6.2	6.1	12.2	12.3	1.3	.7	.7	5.6	.7	6.6	2.2
14	6.4	6.2	12.4	12.5	1.6	.9	.9	5.6	.9	6.8	2.6
16	6.6	6.3	12.7	12.8	1.9	1.0	1.0	5.6	1.0	7.1	3.0
18	6.8	6.3	12.9	13.1	2.2	1.1	1.1	5.6	1.2	7.3	3.4
20	7.0	6.4	13.2	13.5	2.5	1.3	1.3	5.6	1.4	7.6	3.9
22	7.3	6.5	13.5	13.8	2.8	1.4	1.4	5.6	1.6	7.8	4.4
24	7.6	6.6	13.8	14.2	3.2	1.6	1.5	5.7	1.8	8.1	4.9
26	7.9	6.7	14.1	14.6	3.6	1.7	1.7	5.7	2.0	8.5	5.4
28	8.2	6.9	14.5	15.1	4.0	1.9	1.9	5.7	2.2	8.8	5.9
30	8.6	7.0	14.9	15.5	4.4	2.0	2.0	5.7	2.5	9.2	6.5
32	9.0	7.1	15.3	16.1	4.9	2.2	2.2	5.7	2.7	9.6	7.1
34	9.4	7.3	15.8	16.7	5.5	2.3	2.3	5.7	3.0	10.0	7.8
36	9.9	7.4	16.3	17.3	6.0	2.5	2.5	5.8	3.3	10.5	8.4
38	10.4	7.6	16.8	18.0	6.7	2.7	2.7	5.8	3.7	11.1	9.1
40	11.1	7.7	17.4	18.8	7.4	2.9	2.9	5.8	4.1	11.7	9.9
42	11.7	7.9	18.1	19.7	8.2	3.1	3.1	5.8	4.5	12.3	10.7
44	12.5	8.1	18.9	20.7	9.1	3.3	3.3	5.8	5.1	13.1	11.6
46	13.5	8.3	19.8	21.8	10.1	3.5	3.5	5.8	5.6	13.9	12.5
48	14.5	8.5	20.8	23.1	11.3	3.7	3.7	5.9	6.3	14.9	13.6
50	15.8	8.8	22.0	24.6	12.7	4.0	3.9	5.9	7.1	16.1	14.7
52	17.3	9.1	23.4	26.4	14.4	4.2	4.2	5.9	8.0	17.5	15.9
54	19.2	9.4	25.2	28.6	16.5	4.5	4.4	5.9	9.1	19.2	17.3
56	21.7	9.7	27.4	31.4	19.1	4.8	4.7	6.0	10.6	21.4	18.9
58	25.0	10.1	30.3	35.0	22.6	5.1	5.0	6.0	12.5	24.3	20.7
60	29.7	10.5	34.4	40.1	27.5	5.4	5.4	6.0	15.3	28.4	22.8
62	37.2	11.0	41.0	48.2	35.3	5.8	5.8	6.1	19.6	34.9	25.5
64	52.3	11.7	53.9	64.0	50.8	6.3	6.3	6.1	28.2	47.8	29.2
66	114.8	12.9	106.5	127.7	114.0	7.1	7.1	6.2	63.2	100.3	35.6

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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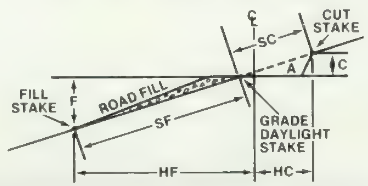
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

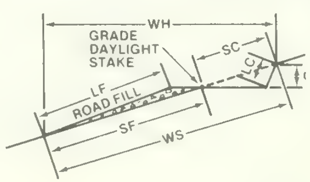
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 11 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.0	6.1	12.0	12.1	1.1	.6	.6	5.7	.6	6.4	1.8
12	6.2	6.2	12.3	12.4	1.3	.8	.7	5.7	.7	6.6	2.2
14	6.4	6.3	12.5	12.7	1.6	.9	.9	5.7	.9	6.8	2.6
16	6.6	6.4	12.8	13.0	1.9	1.0	1.0	5.8	1.0	7.1	3.0
18	6.8	6.5	13.1	13.3	2.2	1.2	1.1	5.8	1.2	7.3	3.5
20	7.1	6.6	13.4	13.7	2.5	1.3	1.3	5.8	1.4	7.6	4.0
22	7.3	6.7	13.7	14.1	2.8	1.5	1.4	5.9	1.6	7.9	4.5
24	7.6	6.8	14.1	14.5	3.2	1.6	1.6	5.9	1.8	8.2	5.0
26	8.0	7.0	14.4	14.9	3.6	1.8	1.8	5.9	2.0	8.5	5.5
28	8.3	7.1	14.8	15.4	4.0	2.0	1.9	6.0	2.2	8.9	6.1
30	8.7	7.3	15.3	15.9	4.5	2.1	2.1	6.0	2.5	9.2	6.7
32	9.1	7.4	15.7	16.5	5.0	2.3	2.3	6.1	2.8	9.7	7.3
34	9.6	7.6	16.2	17.1	5.5	2.5	2.4	6.1	3.1	10.1	8.0
36	10.1	7.8	16.8	17.8	6.1	2.7	2.6	6.2	3.4	10.6	8.7
38	10.6	8.0	17.4	18.6	6.8	2.9	2.8	6.2	3.8	11.2	9.5
40	11.3	8.2	18.0	19.4	7.5	3.1	3.0	6.3	4.2	11.8	10.3
42	12.0	8.4	18.8	20.4	8.4	3.3	3.2	6.3	4.6	12.5	11.2
44	12.8	8.6	19.6	21.4	9.3	3.6	3.5	6.4	5.2	13.3	12.1
46	13.8	8.9	20.6	22.6	10.4	3.8	3.7	6.4	5.8	14.1	13.2
48	14.9	9.1	21.7	24.0	11.6	4.1	3.9	6.5	6.5	15.2	14.3
50	16.2	9.4	22.9	25.7	13.1	4.3	4.2	6.6	7.3	16.4	15.5
52	17.9	9.7	24.5	27.6	14.8	4.6	4.5	6.6	8.2	17.9	16.9
54	19.9	10.1	26.3	29.9	17.0	4.9	4.8	6.7	9.4	19.6	18.4
56	22.4	10.5	28.7	32.9	19.7	5.3	5.1	6.8	11.0	21.9	20.2
58	25.9	10.9	31.8	36.8	23.4	5.7	5.5	6.9	13.0	25.0	22.2
60	30.8	11.5	36.3	42.3	28.6	6.1	5.9	7.0	15.9	29.3	24.7
62	38.8	12.1	43.2	50.9	36.8	6.6	6.4	7.1	20.4	36.1	27.7
64	54.7	12.9	57.0	67.6	53.1	7.2	7.0	7.2	29.5	49.7	31.9
66	120.8	14.3	112.8	135.1	119.9	8.1	7.9	7.5	66.5	105.3	39.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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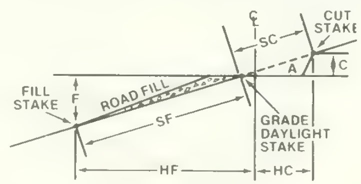
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

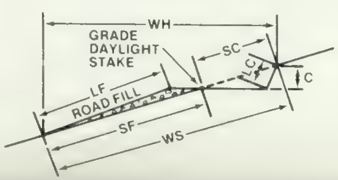
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 11 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.1	6.2	12.2	12.3	1.1	.7	.6	5.8	.6	6.4	1.8
12	6.3	6.3	12.5	12.6	1.3	.8	.8	5.9	.7	6.6	2.2
14	6.5	6.5	12.8	12.9	1.6	1.0	.9	5.9	.9	6.8	2.7
16	6.7	6.6	13.1	13.3	1.9	1.2	1.0	6.0	1.1	7.1	3.1
18	6.9	6.7	13.4	13.7	2.2	1.3	1.2	6.1	1.2	7.3	3.6
20	7.2	6.9	13.8	14.1	2.5	1.5	1.3	6.2	1.4	7.6	4.1
22	7.5	7.0	14.2	14.5	2.9	1.7	1.5	6.3	1.6	7.9	4.6
24	7.8	7.2	14.6	15.0	3.3	1.9	1.7	6.3	1.8	8.2	5.2
26	8.1	7.4	15.0	15.5	3.7	2.1	1.9	6.4	2.0	8.6	5.8
28	8.5	7.6	15.5	16.0	4.1	2.3	2.0	6.5	2.3	8.9	6.4
30	8.9	7.8	15.9	16.6	4.6	2.5	2.2	6.6	2.6	9.3	7.0
32	9.3	8.0	16.5	17.3	5.1	2.7	2.4	6.7	2.8	9.8	7.7
34	9.8	8.2	17.1	18.0	5.7	2.9	2.6	6.8	3.2	10.2	8.5
36	10.4	8.4	17.7	18.8	6.3	3.2	2.9	6.9	3.5	10.8	9.3
38	11.0	8.7	18.4	19.7	7.0	3.5	3.1	7.0	3.9	11.4	10.2
40	11.7	9.0	19.2	20.7	7.8	3.7	3.3	7.2	4.3	12.0	11.1
42	12.5	9.3	20.0	21.7	8.7	4.0	3.6	7.3	4.8	12.7	12.1
44	13.4	9.6	21.0	23.0	9.7	4.3	3.9	7.4	5.4	13.6	13.2
46	14.4	9.9	22.1	24.3	10.9	4.6	4.1	7.6	6.0	14.5	14.4
48	15.6	10.3	23.4	25.9	12.2	5.0	4.5	7.7	6.8	15.6	15.7
50	17.1	10.7	24.9	27.8	13.8	5.4	4.8	7.9	7.6	17.0	17.2
52	18.9	11.1	26.6	30.0	15.7	5.8	5.1	8.1	8.7	18.5	18.8
54	21.0	11.6	28.8	32.7	18.0	6.2	5.5	8.3	10.0	20.5	20.7
56	23.9	12.2	31.5	36.1	21.0	6.7	6.0	8.5	11.7	23.0	22.9
58	27.7	12.8	35.0	40.5	25.0	7.2	6.4	8.7	13.9	26.3	25.4
60	33.1	13.6	40.1	46.7	30.7	7.8	7.0	9.0	17.1	31.1	28.5
62	42.0	14.5	48.0	56.5	39.9	8.5	7.6	9.3	22.1	38.7	32.5
64	59.7	15.7	63.5	75.4	58.0	9.5	8.5	9.7	32.2	53.7	38.0
66	133.4	17.7	126.1	151.1	132.5	10.9	9.7	10.4	73.5	115.7	48.1

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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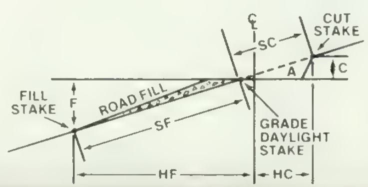
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

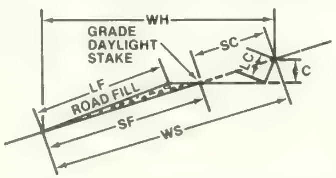
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 11 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.1	6.3	12.4	12.4	1.1	.8	.6	6.0	.6	6.4	1.8
12	6.3	6.5	12.7	12.8	1.4	1.0	.8	6.1	.8	6.6	2.3
14	6.5	6.7	13.0	13.2	1.6	1.2	.9	6.2	.9	6.9	2.7
16	6.8	6.8	13.4	13.6	1.9	1.3	1.1	6.3	1.1	7.1	3.2
18	7.0	7.0	13.8	14.0	2.2	1.5	1.2	6.4	1.2	7.4	3.7
20	7.3	7.2	14.2	14.5	2.6	1.8	1.4	6.6	1.4	7.6	4.2
22	7.6	7.4	14.6	15.0	2.9	2.0	1.6	6.7	1.6	8.0	4.8
24	7.9	7.6	15.1	15.5	3.3	2.2	1.8	6.8	1.9	8.3	5.4
26	8.3	7.8	15.6	16.1	3.8	2.5	2.0	7.0	2.1	8.6	6.0
28	8.7	8.1	16.1	16.8	4.2	2.7	2.2	7.1	2.3	9.0	6.7
30	9.1	8.3	16.7	17.5	4.7	3.0	2.4	7.3	2.6	9.4	7.4
32	9.6	8.6	17.4	18.2	5.3	3.3	2.6	7.5	2.9	9.9	8.2
34	10.1	8.9	18.1	19.1	5.9	3.6	2.9	7.7	3.3	10.4	9.0
36	10.7	9.2	18.8	20.0	6.6	3.9	3.1	7.8	3.6	11.0	9.9
38	11.4	9.6	19.6	21.0	7.3	4.3	3.4	8.1	4.1	11.6	10.9
40	12.2	10.0	20.6	22.1	8.1	4.6	3.7	8.3	4.5	12.3	12.0
42	13.0	10.4	21.6	23.4	9.1	5.0	4.0	8.5	5.0	13.1	13.2
44	14.0	10.8	22.7	24.8	10.2	5.5	4.4	8.8	5.6	14.0	14.5
46	15.2	11.3	24.0	26.5	11.4	5.9	4.7	9.0	6.3	15.0	15.9
48	16.5	11.8	25.6	28.4	12.9	6.4	5.1	9.3	7.1	16.2	17.5
50	18.1	12.4	27.3	30.5	14.6	6.9	5.6	9.7	8.1	17.7	19.3
52	20.1	13.1	29.4	33.2	16.7	7.5	6.0	10.0	9.3	19.4	21.4
54	22.5	13.8	32.0	36.4	19.3	8.2	6.6	10.4	10.7	21.6	23.7
56	25.7	14.6	35.2	40.4	22.6	8.9	7.2	10.9	12.6	24.3	26.5
58	30.0	15.6	39.4	45.6	27.1	9.8	7.8	11.4	15.0	28.1	29.9
60	36.2	16.7	45.4	52.9	33.6	10.8	8.6	12.0	18.6	33.4	34.0
62	46.2	18.1	54.7	64.4	43.9	11.9	9.6	12.7	24.4	42.0	39.4
64	66.5	20.0	72.8	86.5	64.6	13.5	10.8	13.6	35.8	59.3	47.2
66	151.4	23.1	145.6	174.5	150.3	15.9	12.7	15.0	83.4	130.6	62.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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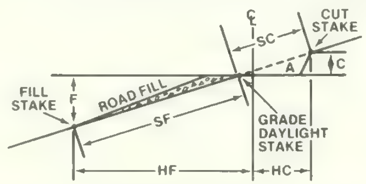
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

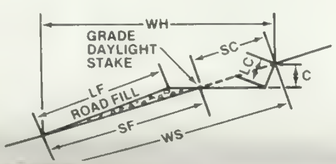
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 11 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.1	6.5	12.6	12.6	1.1	.9	.6	6.1	.6	6.4	1.9
12	6.4	6.7	12.9	13.0	1.4	1.1	.8	6.3	.8	6.6	2.3
14	6.6	6.9	13.3	13.5	1.6	1.3	1.0	6.5	.9	6.9	2.8
16	6.8	7.1	13.7	13.9	2.0	1.6	1.1	6.6	1.1	7.1	3.3
18	7.1	7.3	14.2	14.4	2.3	1.8	1.3	6.8	1.3	7.4	3.8
20	7.4	7.5	14.7	14.9	2.6	2.1	1.5	7.0	1.5	7.7	4.4
22	7.7	7.8	15.2	15.5	3.0	2.4	1.7	7.2	1.7	8.0	5.0
24	8.1	8.1	15.7	16.2	3.4	2.7	1.9	7.4	1.9	8.3	5.6
26	8.5	8.4	16.3	16.9	3.9	3.0	2.1	7.6	2.1	8.7	6.3
28	8.9	8.7	16.9	17.6	4.3	3.3	2.3	7.8	2.4	9.1	7.0
30	9.4	9.0	17.6	18.4	4.9	3.7	2.6	8.1	2.7	9.5	7.9
32	9.9	9.4	18.4	19.3	5.4	4.1	2.9	8.4	3.0	10.0	8.7
34	10.5	9.8	19.2	20.3	6.1	4.5	3.2	8.7	3.4	10.6	9.7
36	11.2	10.3	20.1	21.4	6.8	4.9	3.5	9.0	3.8	11.2	10.7
38	11.9	10.7	21.1	22.6	7.6	5.4	3.8	9.3	4.2	11.8	11.9
40	12.7	11.3	22.3	24.0	8.5	5.9	4.2	9.7	4.7	12.6	13.1
42	13.7	11.8	23.5	25.5	9.5	6.5	4.6	10.1	5.3	13.4	14.5
44	14.8	12.5	25.0	27.3	10.7	7.1	5.0	10.5	6.0	14.4	16.1
46	16.1	13.2	26.6	29.3	12.1	7.8	5.5	11.0	6.7	15.6	17.9
48	17.6	14.0	28.5	31.6	13.7	8.6	6.1	11.6	7.6	16.9	19.9
50	19.4	14.9	30.7	34.3	15.7	9.4	6.7	12.2	8.7	18.5	22.2
52	21.7	15.9	33.3	37.6	18.0	10.4	7.3	12.8	10.0	20.5	24.8
54	24.5	17.1	36.6	41.5	21.0	11.5	8.1	13.6	11.6	22.9	28.0
56	28.2	18.4	40.6	46.6	24.8	12.7	9.0	14.5	13.8	26.1	31.8
58	33.2	20.0	46.0	53.2	30.0	14.2	10.0	15.5	16.6	30.5	36.5
60	40.5	22.0	53.5	62.4	37.5	16.0	11.3	16.8	20.8	36.7	42.5
62	52.4	24.4	65.3	76.8	49.8	18.2	12.9	18.4	27.6	46.9	50.7
64	76.8	27.7	88.0	104.5	74.6	21.2	15.0	20.5	41.4	67.6	62.9
66	179.9	33.5	178.1	213.4	178.7	26.1	18.4	23.9	99.1	154.2	87.6

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
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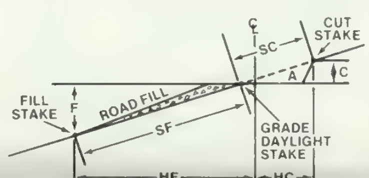
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

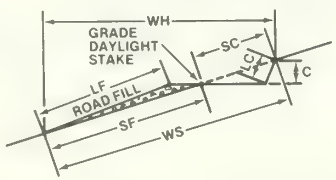
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 11 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.2	6.8	12.9	13.0	1.1	1.2	.7	6.5	.6	6.4	1.9
12	6.5	7.0	13.4	13.5	1.4	1.5	.8	6.8	.8	6.7	2.4
14	6.7	7.3	13.9	14.1	1.7	1.8	1.0	7.0	.9	6.9	2.9
16	7.0	7.6	14.5	14.7	2.0	2.2	1.2	7.3	1.1	7.2	3.4
18	7.3	8.0	15.1	15.3	2.3	2.5	1.4	7.6	1.3	7.5	4.0
20	7.7	8.3	15.7	16.0	2.7	2.9	1.6	8.0	1.5	7.8	4.7
22	8.1	8.7	16.4	16.8	3.1	3.4	1.9	8.3	1.7	8.1	5.4
24	8.5	9.2	17.2	17.7	3.6	3.9	2.1	8.7	2.0	8.5	6.1
26	8.9	9.7	18.0	18.6	4.1	4.4	2.4	9.2	2.2	8.9	7.0
28	9.4	10.2	19.0	19.7	4.6	5.0	2.8	9.6	2.5	9.3	7.9
30	10.0	10.9	20.0	20.9	5.2	5.6	3.1	10.2	2.9	9.8	8.9
32	10.7	11.6	21.2	22.2	5.9	6.3	3.5	10.8	3.2	10.4	10.1
34	11.4	12.3	22.4	23.7	6.6	7.2	4.0	11.5	3.7	11.0	11.4
36	12.2	13.2	23.9	25.4	7.4	8.1	4.5	12.2	4.1	11.7	12.8
38	13.1	14.2	25.6	27.4	8.4	9.1	5.1	13.1	4.7	12.5	14.5
40	14.2	15.4	27.5	29.6	9.5	10.3	5.7	14.1	5.3	13.4	16.4
42	15.5	16.8	29.7	32.2	10.8	11.7	6.5	15.2	6.0	14.5	18.6
44	17.0	18.4	32.4	35.3	12.3	13.4	7.4	16.6	6.8	15.7	21.2
46	18.7	20.3	35.5	39.1	14.1	15.3	8.5	18.2	7.8	17.2	24.3
48	20.9	22.7	39.3	43.6	16.3	17.7	9.8	20.2	9.0	19.1	28.1
50	23.6	25.6	44.0	49.2	19.0	20.6	11.4	22.7	10.6	21.3	32.8
52	27.0	29.3	50.0	56.4	22.5	24.4	13.5	25.8	12.5	24.2	38.7
54	31.6	34.2	57.9	65.8	27.0	29.3	16.3	29.9	15.0	28.0	46.5
56	37.8	41.0	68.7	78.8	33.3	36.1	20.0	35.5	18.5	33.2	57.3
58	46.9	50.9	84.6	97.8	42.4	46.0	25.5	43.8	23.5	40.8	73.1
60	61.5	66.7	110.0	128.3	57.1	61.9	34.3	57.0	31.7	53.0	98.3
62	88.7	96.2	157.1	184.9	84.3	91.4	50.7	81.5	46.7	75.6	145.1
64	156.6	169.9	275.0	326.5	152.2	165.1	91.6	142.9	84.4	132.1	262.1
66	632.2	685.8	1100.0	1318.0	627.8	681.0	377.7	572.1	348.3	527.9	1081.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
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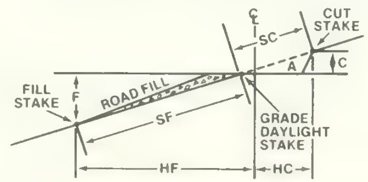
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

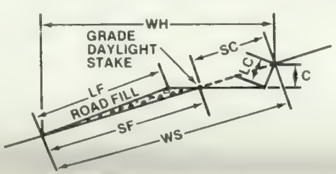
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 12 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.5	6.5	13.0	13.0	1.2	.6	.6	6.0	.6	7.0	2.1
12	6.7	6.6	13.2	13.3	1.4	.8	.8	6.0	.8	7.2	2.6
14	6.9	6.7	13.4	13.6	1.7	.9	.9	6.0	1.0	7.4	3.0
16	7.1	6.7	13.7	13.9	2.0	1.1	1.1	6.0	1.1	7.7	3.5
18	7.4	6.8	14.0	14.2	2.4	1.2	1.2	6.0	1.3	8.0	4.1
20	7.6	6.9	14.2	14.5	2.7	1.4	1.4	6.0	1.5	8.2	4.6
22	7.9	7.0	14.5	14.9	3.1	1.5	1.5	6.0	1.7	8.5	5.1
24	8.2	7.1	14.9	15.3	3.4	1.7	1.7	6.0	1.9	8.9	5.7
26	8.5	7.2	15.2	15.7	3.9	1.8	1.8	6.0	2.1	9.2	6.3
28	8.9	7.3	15.6	16.2	4.3	2.0	2.0	6.0	2.4	9.6	7.0
30	9.3	7.4	16.0	16.7	4.8	2.1	2.1	6.0	2.7	10.0	7.6
32	9.7	7.6	16.4	17.2	5.3	2.3	2.3	6.0	2.9	10.4	8.3
34	10.1	7.7	16.9	17.8	5.9	2.5	2.5	6.0	3.3	10.9	9.0
36	10.7	7.8	17.4	18.5	6.5	2.7	2.7	6.0	3.6	11.4	9.8
38	11.2	8.0	18.0	19.2	7.2	2.8	2.8	6.0	4.0	12.0	10.6
40	11.9	8.2	18.6	20.1	8.0	3.0	3.0	6.0	4.4	12.6	11.5
42	12.6	8.3	19.3	21.0	8.8	3.2	3.2	6.0	4.9	13.3	12.4
44	13.5	8.5	20.1	22.0	9.8	3.4	3.4	6.0	5.4	14.1	13.4
46	14.5	8.7	21.1	23.2	10.9	3.6	3.6	6.0	6.0	15.1	14.5
48	15.6	8.9	22.1	24.5	12.2	3.9	3.9	6.0	6.7	16.1	15.6
50	16.9	9.2	23.4	26.1	13.7	4.1	4.1	6.0	7.6	17.4	16.9
52	18.6	9.4	24.8	28.0	15.4	4.4	4.4	6.0	8.6	18.8	18.2
54	20.6	9.7	26.7	30.3	17.6	4.6	4.6	6.0	9.8	20.7	19.8
56	23.2	10.0	29.0	33.2	20.4	4.9	4.9	6.0	11.3	23.0	21.5
58	26.6	10.4	32.0	37.0	24.1	5.2	5.2	6.0	13.4	26.0	23.5
60	31.6	10.8	36.4	42.4	29.3	5.6	5.6	6.0	16.3	30.4	25.9
62	39.6	11.4	43.3	50.9	37.6	6.0	6.0	6.0	20.8	37.3	28.8
64	55.5	12.0	56.8	67.5	53.9	6.5	6.5	6.0	29.9	50.8	32.8
66	121.4	13.2	112.3	134.5	120.5	7.3	7.3	6.0	66.9	106.3	39.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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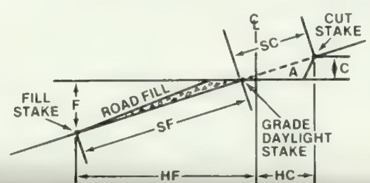
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



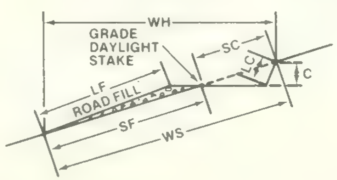
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 12 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.5	6.6	13.0	13.1	1.2	.7	.7	6.1	.7	7.0	2.1
12	6.7	6.6	13.3	13.4	1.4	.8	.8	6.1	.8	7.2	2.6
14	6.9	6.7	13.5	13.7	1.7	.9	.9	6.1	1.0	7.4	3.1
16	7.2	6.8	13.8	14.0	2.0	1.1	1.1	6.1	1.1	7.7	3.6
18	7.4	6.9	14.1	14.3	2.4	1.2	1.2	6.1	1.3	8.0	4.1
20	7.7	7.0	14.4	14.7	2.7	1.4	1.4	6.1	1.5	8.3	4.6
22	7.9	7.1	14.7	15.1	3.1	1.5	1.5	6.2	1.7	8.6	5.2
24	8.2	7.2	15.1	15.5	3.5	1.7	1.7	6.2	1.9	8.9	5.8
26	8.6	7.4	15.4	15.9	3.9	1.9	1.9	6.2	2.2	9.2	6.4
28	8.9	7.5	15.8	16.4	4.3	2.0	2.0	6.2	2.4	9.6	7.1
30	9.3	7.6	16.2	17.0	4.8	2.2	2.2	6.2	2.7	10.0	7.8
32	9.8	7.8	16.7	17.5	5.4	2.4	2.4	6.2	3.0	10.5	8.5
34	10.3	7.9	17.2	18.2	5.9	2.6	2.5	6.3	3.3	11.0	9.2
36	10.8	8.1	17.8	18.9	6.6	2.8	2.7	6.3	3.7	11.5	10.0
38	11.4	8.3	18.4	19.6	7.3	2.9	2.9	6.3	4.0	12.1	10.9
40	12.1	8.4	19.0	20.5	8.1	3.2	3.1	6.3	4.5	12.7	11.8
42	12.8	8.6	19.8	21.5	8.9	3.4	3.3	6.3	5.0	13.4	12.8
44	13.7	8.8	20.6	22.5	9.9	3.6	3.6	6.4	5.5	14.3	13.8
46	14.7	9.1	21.6	23.8	11.1	3.8	3.8	6.4	6.1	15.2	14.9
48	15.8	9.3	22.7	25.2	12.4	4.1	4.0	6.4	6.9	16.3	16.1
50	17.2	9.6	24.0	26.8	13.9	4.3	4.3	6.4	7.7	17.6	17.5
52	18.9	9.9	25.5	28.8	15.7	4.6	4.6	6.5	8.7	19.1	18.9
54	21.0	10.2	27.4	31.2	18.0	4.9	4.8	6.5	10.0	21.0	20.6
56	23.7	10.6	29.8	34.2	20.8	5.2	5.2	6.5	11.6	23.3	22.4
58	27.2	11.0	33.0	38.2	24.6	5.5	5.5	6.6	13.7	26.5	24.6
60	32.4	11.4	37.6	43.8	30.0	5.9	5.9	6.6	16.6	31.0	27.2
62	40.6	12.0	44.7	52.6	38.5	6.4	6.3	6.6	21.4	38.1	30.4
64	57.0	12.8	58.8	69.8	55.4	6.9	6.9	6.7	30.7	52.1	34.7
66	125.2	14.1	116.2	139.3	124.3	7.8	7.7	6.8	69.0	109.5	42.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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WH = TOT. WIDTH DISTURB. HOR.
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LF = LENGTH OF FILL SLOPE
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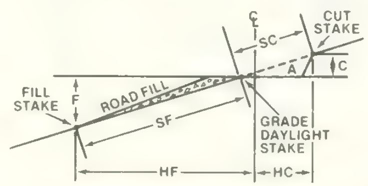
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

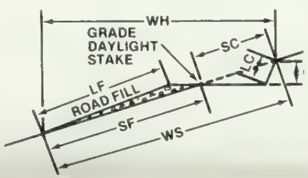
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 12 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.6	6.6	13.1	13.2	1.2	.7	.7	6.2	.7	7.0	2.1
12	6.8	6.7	13.4	13.5	1.5	.8	.8	6.2	.8	7.2	2.6
14	7.0	6.8	13.7	13.8	1.7	1.0	.9	6.2	1.0	7.5	3.1
16	7.2	7.0	14.0	14.2	2.1	1.1	1.1	6.3	1.1	7.7	3.6
18	7.5	7.1	14.3	14.5	2.4	1.3	1.3	6.3	1.3	8.0	4.2
20	7.7	7.2	14.6	14.9	2.7	1.5	1.4	6.4	1.5	8.3	4.7
22	8.0	7.3	15.0	15.3	3.1	1.6	1.6	6.4	1.7	8.6	5.3
24	8.3	7.5	15.4	15.8	3.5	1.8	1.7	6.4	1.9	8.9	5.9
26	8.7	7.6	15.8	16.3	3.9	2.0	1.9	6.5	2.2	9.3	6.6
28	9.1	7.8	16.2	16.8	4.4	2.2	2.1	6.5	2.4	9.7	7.3
30	9.5	7.9	16.6	17.4	4.9	2.3	2.3	6.6	2.7	10.1	8.0
32	9.9	8.1	17.2	18.0	5.4	2.5	2.5	6.6	3.0	10.5	8.7
34	10.4	8.3	17.7	18.7	6.0	2.7	2.7	6.7	3.4	11.0	9.5
36	11.0	8.5	18.3	19.4	6.7	3.0	2.9	6.7	3.7	11.6	10.4
38	11.6	8.7	19.0	20.3	7.4	3.2	3.1	6.8	4.1	12.2	11.3
40	12.3	8.9	19.7	21.2	8.2	3.4	3.3	6.8	4.6	12.9	12.3
42	13.1	9.1	20.5	22.2	9.1	3.6	3.5	6.9	5.1	13.6	13.3
44	14.0	9.4	21.4	23.4	10.2	3.9	3.8	6.9	5.6	14.5	14.4
46	15.0	9.7	22.4	24.7	11.3	4.2	4.0	7.0	6.3	15.4	15.7
48	16.3	10.0	23.6	26.2	12.7	4.4	4.3	7.1	7.0	16.6	17.0
50	17.7	10.3	25.0	28.0	14.3	4.7	4.6	7.1	7.9	17.9	18.5
52	19.5	10.6	26.7	30.1	16.2	5.1	4.9	7.2	9.0	19.5	20.1
54	21.7	11.0	28.7	32.7	18.6	5.4	5.2	7.3	10.3	21.4	21.9
56	24.5	11.4	31.3	35.9	21.5	5.8	5.6	7.4	11.9	23.9	24.0
58	28.2	11.9	34.7	40.2	25.5	6.2	6.0	7.5	14.2	27.2	26.4
60	33.6	12.5	39.6	46.1	31.2	6.6	6.4	7.6	17.3	31.9	29.3
62	42.3	13.2	47.2	55.5	40.2	7.2	7.0	7.7	22.3	39.4	33.0
64	59.7	14.1	62.1	73.8	58.0	7.8	7.6	7.9	32.2	54.2	38.0
66	131.8	15.6	123.0	147.4	130.9	8.9	8.6	8.2	72.6	114.9	47.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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WH = TOT. WIDTH DISTURB. HOR.
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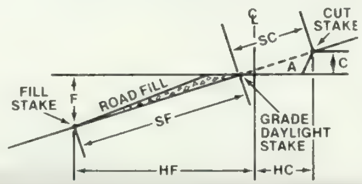
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

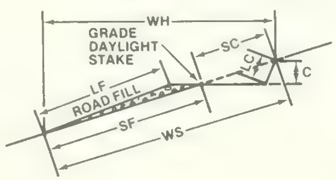
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 12 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.6	6.8	13.3	13.4	1.2	.8	.7	6.3	.7	7.0	2.2
12	6.8	6.9	13.6	13.7	1.5	.9	.8	6.4	.8	7.2	2.7
14	7.0	7.0	14.0	14.1	1.8	1.1	1.0	6.5	1.0	7.5	3.2
16	7.3	7.2	14.3	14.5	2.1	1.3	1.1	6.6	1.2	7.7	3.7
18	7.6	7.3	14.7	14.9	2.4	1.5	1.3	6.7	1.3	8.0	4.3
20	7.8	7.5	15.0	15.3	2.8	1.6	1.5	6.7	1.5	8.3	4.9
22	8.2	7.7	15.5	15.8	3.2	1.8	1.6	6.8	1.8	8.6	5.5
24	8.5	7.9	15.9	16.3	3.6	2.0	1.8	6.9	2.0	9.0	6.2
26	8.9	8.0	16.4	16.9	4.0	2.3	2.0	7.0	2.2	9.3	6.9
28	9.3	8.2	16.9	17.5	4.5	2.5	2.2	7.1	2.5	9.7	7.6
30	9.7	8.5	17.4	18.2	5.0	2.7	2.4	7.2	2.8	10.2	8.4
32	10.2	8.7	18.0	18.9	5.6	3.0	2.6	7.3	3.1	10.7	9.2
34	10.7	8.9	18.6	19.7	6.2	3.2	2.9	7.4	3.5	11.2	10.1
36	11.3	9.2	19.3	20.5	6.9	3.5	3.1	7.6	3.8	11.8	11.1
38	12.0	9.5	20.1	21.5	7.7	3.8	3.4	7.7	4.3	12.4	12.1
40	12.8	9.8	20.9	22.5	8.5	4.1	3.6	7.8	4.7	13.1	13.2
42	13.6	10.1	21.9	23.7	9.5	4.4	3.9	8.0	5.3	13.9	14.4
44	14.6	10.4	22.9	25.0	10.6	4.7	4.2	8.1	5.9	14.8	15.7
46	15.7	10.8	24.1	26.5	11.8	5.1	4.5	8.3	6.6	15.9	17.1
48	17.1	11.2	25.5	28.3	13.3	5.4	4.9	8.4	7.4	17.1	18.7
50	18.6	11.7	27.1	30.3	15.0	5.8	5.2	8.6	8.3	18.5	20.4
52	20.6	12.2	29.0	32.7	17.1	6.3	5.6	8.8	9.5	20.2	22.4
54	23.0	12.7	31.4	35.7	19.7	6.7	6.0	9.0	10.9	22.4	24.6
56	26.0	13.3	34.3	39.4	22.9	7.3	6.5	9.3	12.7	25.1	27.2
58	30.2	14.0	38.2	44.2	27.3	7.9	7.0	9.5	15.1	28.7	30.2
60	36.2	14.8	43.7	51.0	33.5	8.5	7.6	9.8	18.6	33.9	33.9
62	45.8	15.8	52.4	61.6	43.5	9.3	8.3	10.2	24.1	42.2	38.7
64	65.1	17.1	69.2	82.2	63.3	10.3	9.2	10.6	35.1	58.6	45.3
66	145.6	19.3	137.6	164.8	144.5	11.9	10.6	11.3	80.2	126.3	57.3

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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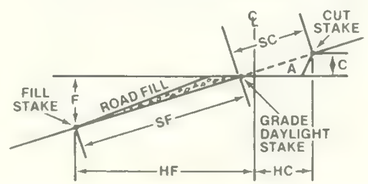
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

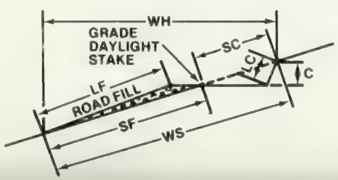
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 12 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.7	6.9	13.5	13.6	1.2	.9	.7	6.5	.7	7.0	2.2
12	6.9	7.1	13.9	14.0	1.5	1.1	.8	6.6	.8	7.2	2.7
14	7.1	7.3	14.2	14.4	1.8	1.3	1.0	6.8	1.0	7.5	3.2
16	7.4	7.4	14.6	14.8	2.1	1.5	1.2	6.9	1.2	7.7	3.8
18	7.7	7.6	15.0	15.3	2.4	1.7	1.4	7.0	1.4	8.0	4.4
20	8.0	7.8	15.5	15.8	2.8	1.9	1.5	7.2	1.6	8.3	5.0
22	8.3	8.1	16.0	16.4	3.2	2.2	1.7	7.3	1.8	8.7	5.7
24	8.7	8.3	16.5	16.9	3.6	2.4	1.9	7.5	2.0	9.0	6.4
26	9.0	8.5	17.0	17.6	4.1	2.7	2.2	7.6	2.3	9.4	7.2
28	9.5	8.8	17.6	18.3	4.6	3.0	2.4	7.8	2.6	9.8	8.0
30	10.0	9.1	18.3	19.1	5.2	3.3	2.6	8.0	2.9	10.3	8.8
32	10.5	9.4	18.9	19.9	5.8	3.6	2.9	8.1	3.2	10.8	9.8
34	11.1	9.7	19.7	20.8	6.4	3.9	3.1	8.4	3.6	11.3	10.8
36	11.7	10.1	20.5	21.8	7.2	4.3	3.4	8.6	4.0	12.0	11.8
38	12.4	10.5	21.4	22.9	8.0	4.6	3.7	8.8	4.4	12.6	13.0
40	13.3	10.9	22.4	24.2	8.9	5.1	4.0	9.0	4.9	13.4	14.3
42	14.2	11.3	23.5	25.5	9.9	5.5	4.4	9.3	5.5	14.3	15.7
44	15.3	11.8	24.8	27.1	11.1	5.9	4.8	9.6	6.2	15.2	17.2
46	16.5	12.3	26.2	28.9	12.5	6.4	5.2	9.9	6.9	16.4	18.9
48	18.0	12.9	27.9	30.9	14.0	7.0	5.6	10.2	7.8	17.7	20.8
50	19.8	13.6	29.8	33.3	15.9	7.6	6.1	10.5	8.8	19.3	23.0
52	21.9	14.3	32.1	36.2	18.2	8.2	6.6	10.9	10.1	21.2	25.4
54	24.6	15.1	34.9	39.7	21.1	9.0	7.2	11.4	11.7	23.5	28.2
56	28.0	16.0	38.4	44.0	24.7	9.8	7.8	11.9	13.7	26.6	31.6
58	32.7	17.0	43.0	49.7	29.6	10.7	8.5	12.4	16.4	30.6	35.5
60	39.5	18.3	49.5	57.8	36.6	11.7	9.4	13.0	20.3	36.5	40.5
62	50.4	19.8	59.7	70.2	47.9	13.0	10.4	13.8	26.6	45.9	46.9
64	72.5	21.8	79.5	94.3	70.5	14.7	11.8	14.8	39.1	64.6	56.2
66	165.1	25.2	158.8	190.3	164.0	17.4	13.9	16.4	91.0	142.4	73.7

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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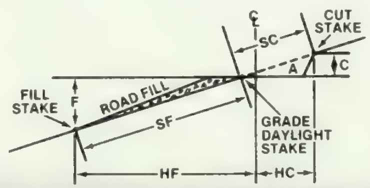
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

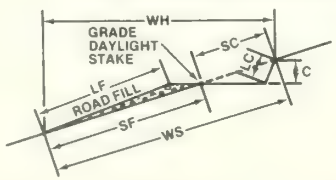
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 12 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.7	7.1	13.7	13.8	1.2	1.0	.7	6.7	.7	7.0	2.2
12	6.9	7.3	14.1	14.2	1.5	1.2	.9	6.9	.8	7.2	2.7
14	7.2	7.5	14.5	14.7	1.8	1.5	1.0	7.0	1.0	7.5	3.3
16	7.5	7.7	15.0	15.2	2.1	1.7	1.2	7.2	1.2	7.8	3.9
18	7.8	8.0	15.5	15.7	2.5	2.0	1.4	7.4	1.4	8.1	4.5
20	8.1	8.2	16.0	16.3	2.9	2.3	1.6	7.6	1.6	8.4	5.2
22	8.4	8.5	16.5	16.9	3.3	2.6	1.8	7.8	1.8	8.7	5.9
24	8.8	8.8	17.1	17.6	3.7	2.9	2.1	8.1	2.1	9.1	6.7
26	9.3	9.1	17.8	18.4	4.2	3.2	2.3	8.3	2.3	9.5	7.5
28	9.7	9.5	18.5	19.2	4.7	3.6	2.6	8.6	2.6	9.9	8.4
30	10.2	9.8	19.2	20.1	5.3	4.0	2.8	8.8	2.9	10.4	9.3
32	10.8	10.3	20.1	21.1	5.9	4.4	3.1	9.1	3.3	10.9	10.4
34	11.5	10.7	21.0	22.2	6.6	4.9	3.4	9.4	3.7	11.5	11.5
36	12.2	11.2	22.0	23.3	7.4	5.4	3.8	9.8	4.1	12.2	12.8
38	13.0	11.7	23.1	24.7	8.3	5.9	4.2	10.2	4.6	12.9	14.1
40	13.9	12.3	24.3	26.2	9.3	6.5	4.6	10.6	5.2	13.7	15.6
42	14.9	12.9	25.7	27.8	10.4	7.1	5.0	11.0	5.8	14.7	17.3
44	16.1	13.6	27.2	29.7	11.7	7.8	5.5	11.5	6.5	15.7	19.2
46	17.5	14.4	29.0	31.9	13.2	8.5	6.0	12.0	7.3	17.0	21.3
48	19.2	15.3	31.1	34.5	15.0	9.3	6.6	12.6	8.3	18.5	23.6
50	21.2	16.2	33.5	37.4	17.1	10.3	7.3	13.3	9.5	20.2	26.4
52	23.6	17.3	36.4	41.0	19.7	11.3	8.0	14.0	10.9	22.4	29.6
54	26.7	18.6	39.9	45.3	22.9	12.5	8.8	14.8	12.7	25.0	33.3
56	30.7	20.1	44.3	50.8	27.1	13.9	9.8	15.8	15.0	28.5	37.9
58	36.2	21.8	50.2	58.0	32.7	15.5	11.0	17.0	18.2	33.2	43.4
60	44.2	23.9	58.4	68.1	41.0	17.4	12.3	18.3	22.7	40.1	50.6
62	57.2	26.6	71.2	83.8	54.3	19.8	14.0	20.0	30.1	51.2	60.3
64	83.7	30.3	96.0	114.0	81.4	23.1	16.3	22.3	45.1	73.7	74.9
66	196.3	36.5	194.3	232.8	194.9	28.4	20.1	26.1	108.1	168.2	104.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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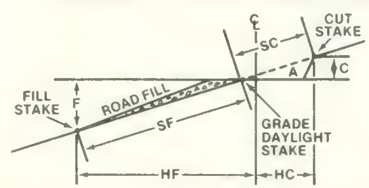
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

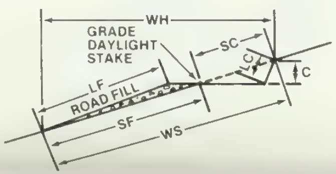
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 12 FEET

CUT SLOPE = 1.5 TO 1

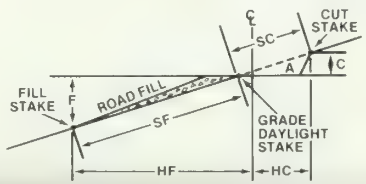
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	6.8	7.4	14.1	14.2	1.2	1.3	.7	7.1	.7	7.0	2.3
12	7.1	7.7	14.6	14.7	1.5	1.6	.9	7.4	.8	7.3	2.9
14	7.4	8.0	15.2	15.3	1.8	2.0	1.1	7.7	1.0	7.5	3.5
16	7.7	8.3	15.8	16.0	2.2	2.4	1.3	8.0	1.2	7.8	4.1
18	8.0	8.7	16.4	16.7	2.6	2.8	1.5	8.3	1.4	8.1	4.8
20	8.4	9.1	17.1	17.5	3.0	3.2	1.8	8.7	1.6	8.5	5.6
22	8.8	9.5	17.9	18.3	3.4	3.7	2.1	9.1	1.9	8.8	6.4
24	9.2	10.0	18.8	19.3	3.9	4.2	2.3	9.5	2.2	9.2	7.3
26	9.8	10.6	19.7	20.3	4.4	4.8	2.7	10.0	2.5	9.7	8.3
28	10.3	11.2	20.7	21.5	5.0	5.4	3.0	10.5	2.8	10.2	9.4
30	10.9	11.9	21.8	22.8	5.7	6.1	3.4	11.1	3.1	10.7	10.6
32	11.6	12.6	23.1	24.2	6.4	6.9	3.8	11.8	3.5	11.3	12.0
34	12.4	13.5	24.5	25.9	7.2	7.8	4.3	12.5	4.0	12.0	13.5
36	13.3	14.4	26.1	27.7	8.1	8.8	4.9	13.3	4.5	12.8	15.3
38	14.3	15.5	27.9	29.9	9.2	9.9	5.5	14.3	5.1	13.6	17.2
40	15.5	16.8	30.0	32.3	10.4	11.3	6.2	15.4	5.8	14.6	19.5
42	16.9	18.3	32.4	35.2	11.8	12.8	7.1	16.6	6.5	15.8	22.1
44	18.5	20.1	35.3	38.6	13.4	14.6	8.1	18.1	7.4	17.2	25.2
46	20.4	22.2	38.7	42.6	15.4	16.7	9.3	19.9	8.5	18.8	28.9
48	22.8	24.7	42.9	47.5	17.8	19.3	10.7	22.1	9.9	20.8	33.4
50	25.7	27.9	48.0	53.7	20.8	22.5	12.5	24.7	11.5	23.3	39.0
52	29.5	32.0	54.5	61.5	24.5	26.6	14.8	28.1	13.6	26.4	46.1
54	34.4	37.3	63.2	71.8	29.5	32.0	17.7	32.6	16.4	30.5	55.4
56	41.2	44.7	75.0	86.0	36.3	39.4	21.9	38.8	20.1	36.2	68.2
58	51.2	55.5	92.3	106.7	46.3	50.2	27.9	47.8	25.7	44.5	87.0
60	67.1	72.8	120.0	139.9	62.3	67.5	37.5	62.2	34.5	57.8	116.9
62	96.8	104.9	171.4	201.7	91.9	99.7	55.3	89.0	51.0	82.5	172.6
64	170.9	185.3	300.0	356.2	166.0	180.1	99.9	155.8	92.1	144.2	311.9
66	689.7	748.1	1200.0	1437.8	684.9	742.9	412.1	624.1	379.9	575.9	1286.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

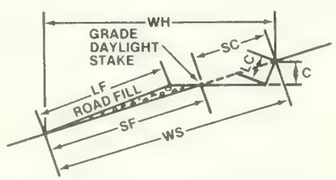
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 13 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.1	7.1	14.1	14.1	1.3	.7	.7	6.5	.7	7.6	2.5
12	7.3	7.1	14.3	14.4	1.6	.9	.9	6.5	.9	7.8	3.0
14	7.5	7.2	14.6	14.7	1.9	1.0	1.0	6.5	1.0	8.1	3.6
16	7.7	7.3	14.8	15.0	2.2	1.2	1.2	6.5	1.2	8.3	4.2
18	8.0	7.4	15.1	15.4	2.5	1.3	1.3	6.5	1.4	8.6	4.8
20	8.2	7.5	15.4	15.7	2.9	1.5	1.5	6.5	1.6	8.9	5.4
22	8.5	7.6	15.8	16.1	3.3	1.6	1.6	6.5	1.8	9.3	6.0
24	8.9	7.7	16.1	16.6	3.7	1.8	1.8	6.5	2.1	9.6	6.7
26	9.2	7.8	16.5	17.0	4.2	2.0	2.0	6.5	2.3	10.0	7.4
28	9.6	7.9	16.9	17.5	4.7	2.1	2.1	6.5	2.6	10.4	8.2
30	10.0	8.1	17.3	18.1	5.2	2.3	2.3	6.5	2.9	10.8	8.9
32	10.5	8.2	17.8	18.7	5.8	2.5	2.5	6.5	3.2	11.3	9.8
34	11.0	8.3	18.3	19.3	6.4	2.7	2.7	6.5	3.5	11.8	10.6
36	11.6	8.5	18.9	20.1	7.1	2.9	2.9	6.5	3.9	12.4	11.5
38	12.2	8.7	19.5	20.9	7.8	3.1	3.1	6.5	4.3	13.0	12.5
40	12.9	8.8	20.2	21.7	8.6	3.3	3.3	6.5	4.8	13.7	13.5
42	13.7	9.0	21.0	22.7	9.6	3.5	3.5	6.5	5.3	14.5	14.6
44	14.6	9.2	21.8	23.8	10.6	3.7	3.7	6.5	5.9	15.3	15.7
46	15.7	9.5	22.8	25.1	11.8	4.0	4.0	6.5	6.5	16.3	17.0
48	16.9	9.7	24.0	26.6	13.2	4.2	4.2	6.5	7.3	17.5	18.3
50	18.3	9.9	25.3	28.3	14.8	4.4	4.4	6.5	8.2	18.8	19.8
52	20.1	10.2	26.9	30.3	16.7	4.7	4.7	6.5	9.3	20.4	21.4
54	22.3	10.5	28.9	32.8	19.1	5.0	5.0	6.5	10.6	22.4	23.2
56	25.1	10.9	31.4	36.0	22.1	5.3	5.3	6.5	12.3	24.9	25.3
58	28.8	11.3	34.7	40.1	26.1	5.7	5.7	6.5	14.5	28.2	27.6
60	34.2	11.7	39.4	46.0	31.7	6.0	6.0	6.5	17.6	32.9	30.4
62	42.8	12.3	46.9	55.1	40.7	6.5	6.5	6.5	22.6	40.4	33.9
64	60.1	13.0	61.6	73.1	58.4	7.0	7.0	6.5	32.4	55.1	38.6
66	131.5	14.3	121.6	145.7	130.6	7.9	7.9	6.5	72.4	115.1	46.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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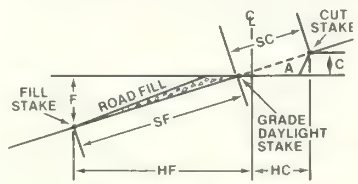
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

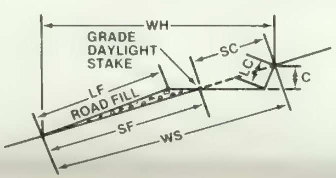
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 13 FEET

CUT SLOPE = .10 TO 1

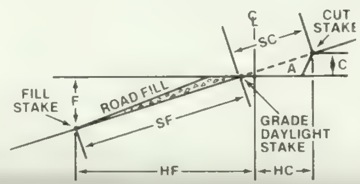
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.1	7.1	14.1	14.2	1.3	.7	.7	6.6	.7	7.6	2.5
12	7.3	7.2	14.4	14.5	1.6	.9	.9	6.6	.9	7.8	3.0
14	7.5	7.3	14.7	14.8	1.9	1.0	1.0	6.6	1.0	8.1	3.6
16	7.8	7.4	15.0	15.1	2.2	1.2	1.2	6.6	1.2	8.3	4.2
18	8.0	7.5	15.3	15.5	2.6	1.3	1.3	6.6	1.4	8.6	4.8
20	8.3	7.6	15.6	15.9	2.9	1.5	1.5	6.6	1.6	8.9	5.4
22	8.6	7.7	15.9	16.3	3.3	1.7	1.7	6.7	1.8	9.3	6.1
24	8.9	7.8	16.3	16.8	3.8	1.8	1.8	6.7	2.1	9.6	6.8
26	9.3	8.0	16.7	17.3	4.2	2.0	2.0	6.7	2.3	10.0	7.5
28	9.7	8.1	17.1	17.8	4.7	2.2	2.2	6.7	2.6	10.4	8.3
30	10.1	8.3	17.6	18.4	5.2	2.4	2.4	6.7	2.9	10.9	9.1
32	10.6	8.4	18.1	19.0	5.8	2.6	2.6	6.8	3.2	11.3	9.9
34	11.1	8.6	18.6	19.7	6.4	2.8	2.8	6.8	3.6	11.9	10.8
36	11.7	8.8	19.2	20.4	7.1	3.0	3.0	6.8	4.0	12.4	11.8
38	12.3	8.9	19.9	21.3	7.9	3.2	3.2	6.8	4.4	13.1	12.8
40	13.1	9.1	20.6	22.2	8.7	3.4	3.4	6.8	4.9	13.8	13.8
42	13.9	9.4	21.4	23.2	9.7	3.6	3.6	6.9	5.4	14.6	15.0
44	14.8	9.6	22.3	24.4	10.8	3.9	3.9	6.9	6.0	15.5	16.2
46	15.9	9.8	23.4	25.7	12.0	4.1	4.1	6.9	6.6	16.5	17.5
48	17.2	10.1	24.6	27.3	13.4	4.4	4.4	6.9	7.4	17.6	18.9
50	18.7	10.4	26.0	29.1	15.1	4.7	4.6	7.0	8.3	19.0	20.5
52	20.5	10.7	27.7	31.2	17.0	5.0	4.9	7.0	9.5	20.7	22.2
54	22.7	11.1	29.7	33.8	19.5	5.3	5.3	7.0	10.8	22.7	24.2
56	25.6	11.4	32.3	37.1	22.6	5.6	5.6	7.1	12.5	25.3	26.3
58	29.5	11.9	35.8	41.4	26.7	6.0	6.0	7.1	14.8	28.7	28.9
60	35.0	12.4	40.7	47.4	32.5	6.4	6.4	7.1	18.0	33.5	31.9
62	44.0	13.0	48.4	57.0	41.8	6.9	6.9	7.2	23.2	41.2	35.6
64	61.8	13.9	63.7	75.6	60.0	7.5	7.5	7.2	33.3	56.4	40.8
66	135.7	15.2	125.9	150.9	134.7	8.4	8.4	7.3	74.7	118.6	49.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

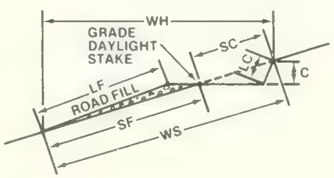
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 13 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.1	7.2	14.2	14.3	1.3	.7	.7	6.7	.7	7.6	2.5
12	7.3	7.3	14.5	14.6	1.6	.9	.9	6.7	.9	7.8	3.1
14	7.6	7.4	14.8	15.0	1.9	1.1	1.0	6.8	1.0	8.1	3.6
16	7.8	7.5	15.1	15.3	2.2	1.2	1.2	6.8	1.2	8.4	4.3
18	8.1	7.7	15.5	15.7	2.6	1.4	1.4	6.8	1.4	8.6	4.9
20	8.4	7.8	15.8	16.2	3.0	1.6	1.5	6.9	1.6	9.0	5.5
22	8.7	7.9	16.2	16.6	3.4	1.8	1.7	6.9	1.9	9.3	6.2
24	9.0	8.1	16.6	17.1	3.8	1.9	1.9	7.0	2.1	9.7	7.0
26	9.4	8.2	17.1	17.6	4.3	2.1	2.1	7.0	2.4	10.0	7.7
28	9.8	8.4	17.5	18.2	4.8	2.3	2.3	7.1	2.6	10.5	8.5
30	10.3	8.6	18.0	18.8	5.3	2.5	2.5	7.1	2.9	10.9	9.4
32	10.7	8.8	18.6	19.5	5.9	2.8	2.7	7.2	3.3	11.4	10.3
34	11.3	9.0	19.2	20.3	6.6	3.0	2.9	7.2	3.6	12.0	11.2
36	11.9	9.2	19.8	21.1	7.3	3.2	3.1	7.3	4.0	12.5	12.2
38	12.6	9.4	20.5	22.0	8.0	3.4	3.3	7.3	4.5	13.2	13.3
40	13.3	9.6	21.3	23.0	8.9	3.7	3.6	7.4	4.9	13.9	14.4
42	14.2	9.9	22.2	24.1	9.9	3.9	3.8	7.5	5.5	14.7	15.6
44	15.2	10.2	23.2	25.3	11.0	4.2	4.1	7.5	6.1	15.7	17.0
46	16.3	10.5	24.3	26.8	12.3	4.5	4.4	7.6	6.8	16.7	18.4
48	17.6	10.8	25.6	28.4	13.7	4.8	4.7	7.7	7.6	17.9	19.9
50	19.2	11.1	27.1	30.3	15.5	5.1	5.0	7.7	8.6	19.4	21.7
52	21.1	11.5	28.9	32.6	17.5	5.5	5.3	7.8	9.7	21.1	23.6
54	23.5	11.9	31.1	35.4	20.1	5.8	5.7	7.9	11.1	23.2	25.7
56	26.5	12.4	33.9	38.9	23.3	6.2	6.1	8.0	12.9	25.9	28.2
58	30.6	12.9	37.6	43.5	27.6	6.7	6.5	8.1	15.3	29.5	31.0
60	36.4	13.6	42.9	50.0	33.8	7.2	7.0	8.2	18.7	34.6	34.4
62	45.8	14.3	51.1	60.1	43.5	7.8	7.5	8.4	24.1	42.7	38.7
64	64.6	15.3	67.3	79.9	62.8	8.5	8.2	8.6	34.8	58.8	44.6
66	142.8	16.9	133.3	159.7	141.8	9.6	9.3	8.8	78.6	124.5	55.1

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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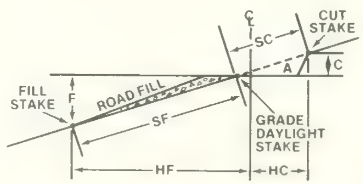
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

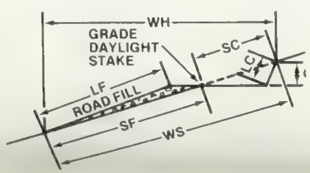
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 13 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.2	7.3	14.4	14.5	1.3	.8	.7	6.9	.7	7.6	2.5
12	7.4	7.5	14.8	14.9	1.6	1.0	.9	6.9	.9	7.8	3.1
14	7.6	7.6	15.1	15.3	1.9	1.2	1.1	7.0	1.1	8.1	3.7
16	7.9	7.8	15.5	15.7	2.2	1.4	1.2	7.1	1.2	8.4	4.4
18	8.2	8.0	15.9	16.1	2.6	1.6	1.4	7.2	1.4	8.7	5.0
20	8.5	8.1	16.3	16.6	3.0	1.8	1.6	7.3	1.7	9.0	5.7
22	8.8	8.3	16.7	17.1	3.4	2.0	1.8	7.4	1.9	9.3	6.4
24	9.2	8.5	17.2	17.7	3.9	2.2	2.0	7.5	2.1	9.7	7.2
26	9.6	8.7	17.7	18.3	4.4	2.5	2.2	7.6	2.4	10.1	8.0
28	10.0	8.9	18.3	19.0	4.9	2.7	2.4	7.7	2.7	10.6	8.9
30	10.5	9.2	18.8	19.7	5.4	2.9	2.6	7.8	3.0	11.0	9.8
32	11.0	9.4	19.5	20.5	6.1	3.2	2.9	7.9	3.4	11.5	10.8
34	11.6	9.7	20.2	21.3	6.7	3.5	3.1	8.1	3.7	12.1	11.9
36	12.3	10.0	20.9	22.2	7.5	3.8	3.4	8.2	4.2	12.7	13.0
38	13.0	10.3	21.7	23.3	8.3	4.1	3.6	8.3	4.6	13.4	14.2
40	13.8	10.6	22.7	24.4	9.2	4.4	3.9	8.5	5.1	14.2	15.5
42	14.7	10.9	23.7	25.7	10.3	4.7	4.2	8.6	5.7	15.1	16.9
44	15.8	11.3	24.8	27.1	11.5	5.1	4.6	8.8	6.4	16.0	18.4
46	17.0	11.7	26.1	28.8	12.8	5.5	4.9	8.9	7.1	17.2	20.1
48	18.5	12.2	27.6	30.6	14.4	5.9	5.3	9.1	8.0	18.5	21.9
50	20.2	12.6	29.4	32.8	16.3	6.3	5.7	9.3	9.0	20.0	24.0
52	22.3	13.2	31.5	35.5	18.5	6.8	6.1	9.5	10.3	21.9	26.3
54	24.9	13.8	34.0	38.6	21.3	7.3	6.5	9.8	11.8	24.2	28.9
56	28.2	14.4	37.2	42.6	24.8	7.9	7.0	10.0	13.8	27.2	31.9
58	32.7	15.2	41.4	47.9	29.6	8.5	7.6	10.3	16.4	31.1	35.5
60	39.2	16.1	47.4	55.2	36.3	9.2	8.3	10.6	20.2	36.7	39.8
62	49.6	17.1	56.7	66.7	47.1	10.1	9.0	11.0	26.1	45.7	45.4
64	70.5	18.5	75.0	89.1	68.5	11.2	10.0	11.5	38.0	63.5	53.1
66	157.7	20.9	149.0	178.6	156.6	12.9	11.5	12.3	86.9	136.8	67.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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WH = TOT. WIDTH DISTURB. HOR.
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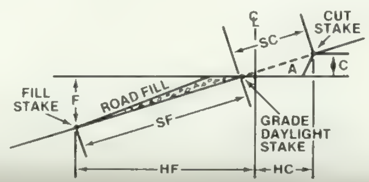
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

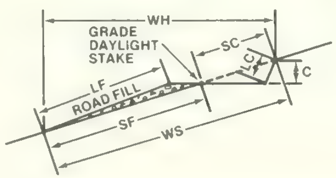
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 13 FEET

CUT SLOPE = .75 TO 1

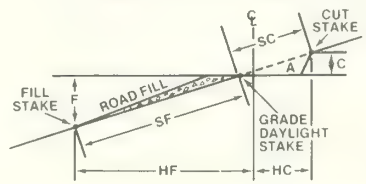
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.2	7.5	14.6	14.7	1.3	.9	.7	7.1	.7	7.6	2.6
12	7.5	7.7	15.0	15.1	1.6	1.1	.9	7.2	.9	7.8	3.2
14	7.7	7.9	15.4	15.6	1.9	1.4	1.1	7.3	1.1	8.1	3.8
16	8.0	8.1	15.8	16.1	2.3	1.6	1.3	7.5	1.3	8.4	4.5
18	8.3	8.3	16.3	16.6	2.6	1.8	1.5	7.6	1.5	8.7	5.2
20	8.6	8.5	16.8	17.1	3.1	2.1	1.7	7.7	1.7	9.0	5.9
22	9.0	8.7	17.3	17.7	3.5	2.3	1.9	7.9	1.9	9.4	6.7
24	9.4	9.0	17.9	18.4	3.9	2.6	2.1	8.1	2.2	9.8	7.5
26	9.8	9.3	18.4	19.1	4.4	2.9	2.3	8.2	2.5	10.2	8.4
28	10.3	9.5	19.1	19.8	5.0	3.2	2.6	8.4	2.8	10.7	9.3
30	10.8	9.9	19.8	20.6	5.6	3.5	2.8	8.6	3.1	11.1	10.4
32	11.4	10.2	20.5	21.5	6.2	3.9	3.1	8.8	3.5	11.7	11.5
34	12.0	10.5	21.3	22.5	7.0	4.2	3.4	9.0	3.9	12.3	12.6
36	12.7	10.9	22.2	23.6	7.8	4.6	3.7	9.3	4.3	12.9	13.9
38	13.5	11.3	23.2	24.8	8.6	5.0	4.0	9.5	4.8	13.7	15.3
40	14.4	11.8	24.3	26.2	9.6	5.5	4.4	9.8	5.3	14.5	16.8
42	15.4	12.3	25.5	27.7	10.7	5.9	4.8	10.1	6.0	15.4	19.4
44	16.6	12.8	26.9	29.4	12.0	6.4	5.2	10.4	6.7	16.5	20.2
46	17.9	13.4	28.4	31.3	13.5	7.0	5.6	10.7	7.5	17.7	22.2
48	19.5	14.0	30.2	33.5	15.2	7.6	6.1	11.0	8.4	19.2	24.5
50	21.4	14.7	32.3	36.1	17.3	8.2	6.6	11.4	9.6	20.9	27.0
52	23.7	15.5	34.8	39.2	19.7	8.9	7.1	11.8	11.0	22.9	29.8
54	26.6	16.3	37.8	43.0	22.8	9.7	7.8	12.3	12.7	25.5	33.1
56	30.4	17.3	41.6	47.7	26.8	10.6	8.5	12.8	14.8	28.8	37.0
58	35.4	18.4	46.6	53.9	32.1	11.6	9.3	13.4	17.8	33.2	41.7
60	42.8	19.8	53.7	62.6	39.7	12.7	10.2	14.1	22.0	39.5	47.5
62	54.6	21.4	64.7	76.1	51.9	14.1	11.3	15.0	28.8	49.7	55.1
64	78.6	23.6	86.1	102.2	76.4	15.9	12.7	16.1	42.4	70.0	66.0
66	178.9	27.3	172.1	206.2	177.6	18.8	15.0	17.8	98.5	154.3	86.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

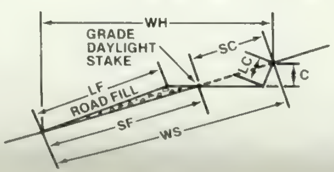
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 13 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.3	7.7	14.8	14.9	1.3	1.1	.8	7.3	.7	7.6	2.6
12	7.5	7.9	15.3	15.4	1.6	1.3	.9	7.4	.9	7.8	3.2
14	7.8	8.1	15.7	15.9	1.9	1.6	1.1	7.6	1.1	8.1	3.9
16	8.1	8.4	16.2	16.4	2.3	1.9	1.3	7.8	1.3	8.4	4.6
18	8.4	8.6	16.8	17.0	2.7	2.2	1.5	8.0	1.5	8.7	5.3
20	8.8	8.9	17.3	17.7	3.1	2.5	1.7	8.2	1.7	9.1	6.1
22	9.2	9.2	17.9	18.4	3.5	2.8	2.0	8.5	2.0	9.5	6.9
24	9.6	9.5	18.6	19.1	4.0	3.1	2.2	8.7	2.2	9.9	7.8
26	10.0	9.9	19.3	19.9	4.6	3.5	2.5	9.0	2.5	10.3	8.8
28	10.5	10.3	20.0	20.8	5.1	3.9	2.8	9.3	2.8	10.8	9.8
30	11.1	10.7	20.8	21.8	5.7	4.3	3.1	9.6	3.2	11.3	11.0
32	11.7	11.1	21.7	22.8	6.4	4.8	3.4	9.9	3.6	11.9	12.2
34	12.4	11.6	22.7	24.0	7.2	5.3	3.7	10.2	4.0	12.5	13.5
36	13.2	12.1	23.8	25.3	8.0	5.8	4.1	10.6	4.5	13.2	15.0
38	14.0	12.7	25.0	26.7	9.0	6.4	4.5	11.0	5.0	14.0	16.6
40	15.0	13.3	26.3	28.3	10.1	7.0	4.9	11.4	5.6	14.9	18.3
42	16.2	14.0	27.8	30.2	11.3	7.7	5.4	11.9	6.3	15.9	20.3
44	17.5	14.8	29.5	32.2	12.7	8.4	5.9	12.4	7.0	17.0	22.5
46	19.0	15.6	31.4	34.6	14.3	9.2	6.5	13.0	7.9	18.4	24.9
48	20.8	16.5	33.6	37.3	16.2	10.1	7.2	13.7	9.0	20.0	27.8
50	22.9	17.6	36.3	40.5	18.5	11.1	7.9	14.4	10.3	21.9	31.0
52	25.6	18.8	39.4	44.4	21.3	12.3	8.7	15.2	11.8	24.2	34.7
54	28.9	20.2	43.2	49.1	24.8	13.6	9.6	16.1	13.7	27.1	39.1
56	33.3	21.8	48.0	55.0	29.3	15.0	10.6	17.1	16.3	30.9	44.4
58	39.2	23.7	54.4	62.8	35.4	16.8	11.9	18.4	19.7	36.0	51.0
60	47.8	25.9	63.3	73.8	44.4	18.9	13.3	19.8	24.6	43.4	59.4
62	62.0	28.8	77.2	90.8	58.9	21.5	15.2	21.7	32.6	55.5	70.8
64	90.7	32.8	104.0	123.5	88.1	25.0	17.7	24.2	48.9	79.8	87.9
66	212.7	39.6	210.5	252.2	211.2	30.8	21.8	28.3	117.1	182.2	122.3

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
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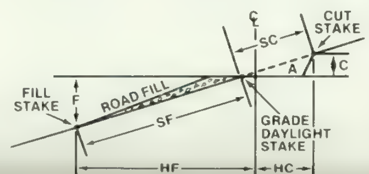
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

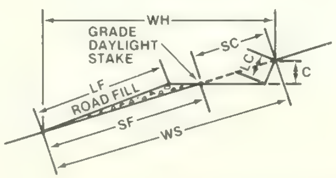
... DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 13 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.4	8.0	15.3	15.4	1.3	1.4	.8	7.7	.7	7.6	2.7
12	7.7	8.3	15.9	16.0	1.6	1.8	1.0	8.0	.9	7.9	3.3
14	8.0	8.6	16.5	16.6	2.0	2.2	1.2	8.3	1.1	8.2	4.1
16	8.3	9.0	17.1	17.3	2.4	2.6	1.4	8.6	1.3	8.5	4.8
18	8.7	9.4	17.8	18.1	2.8	3.0	1.7	9.0	1.5	8.8	5.6
20	9.1	9.9	18.6	18.9	3.2	3.5	1.9	9.4	1.8	9.2	6.5
22	9.5	10.3	19.4	19.9	3.7	4.0	2.2	9.8	2.0	9.6	7.5
24	10.0	10.9	20.3	20.9	4.2	4.6	2.5	10.3	2.3	10.0	8.6
26	10.6	11.5	21.3	22.0	4.8	5.2	2.9	10.8	2.7	10.5	9.8
28	11.2	12.1	22.4	23.3	5.4	5.9	3.3	11.4	3.0	11.0	11.0
30	11.8	12.8	23.6	24.7	6.1	6.7	3.7	12.0	3.4	11.6	12.5
32	12.6	13.7	25.0	26.2	6.9	7.5	4.2	12.7	3.8	12.3	14.1
34	13.4	14.6	26.5	28.0	7.8	8.5	4.7	13.5	4.3	13.0	15.9
36	14.4	15.6	28.3	30.0	8.8	9.5	5.3	14.4	4.9	13.8	17.9
38	15.5	16.8	30.2	32.3	9.9	10.8	6.0	15.5	5.5	14.8	20.2
40	16.8	18.2	32.5	35.0	11.2	12.2	6.8	16.6	6.2	15.9	22.9
42	18.3	19.8	35.1	38.1	12.8	13.8	7.7	18.0	7.1	17.1	26.0
44	20.0	21.7	38.2	41.8	14.5	15.8	8.8	19.6	8.1	18.6	29.6
46	22.1	24.0	41.9	46.2	16.7	18.1	10.0	21.6	9.3	20.4	33.9
48	24.7	26.8	46.4	51.5	19.3	20.9	11.6	23.9	10.7	22.5	39.2
50	27.9	30.2	52.0	58.1	22.5	24.4	13.5	26.8	12.5	25.2	45.8
52	31.9	34.7	59.1	66.6	26.6	28.8	16.0	30.5	14.7	28.6	54.1
54	37.3	40.5	68.4	77.8	32.0	34.7	19.2	35.3	17.7	33.1	65.0
56	44.7	48.5	81.2	93.1	39.3	42.7	23.7	42.0	21.8	39.2	80.1
58	55.5	60.1	100.0	115.6	50.2	54.4	30.2	51.8	27.8	48.2	102.1
60	72.7	78.9	130.0	151.6	67.5	73.2	40.6	67.4	37.4	62.6	137.3
62	104.8	113.7	185.7	218.5	99.6	108.0	59.9	96.4	55.2	89.4	202.6
64	185.1	200.8	325.0	385.9	179.9	195.1	108.2	168.8	99.8	156.2	366.0
66	747.2	810.4	1300.0	1557.6	742.0	804.8	446.4	676.1	411.6	623.9	1509.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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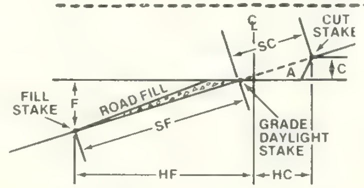
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

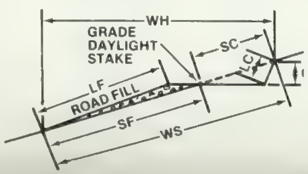
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 14 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.6	7.6	15.1	15.2	1.4	.8	.8	7.0	.8	8.1	2.9
12	7.8	7.7	15.4	15.5	1.7	.9	.9	7.0	.9	8.4	3.5
14	8.1	7.8	15.7	15.8	2.0	1.1	1.1	7.0	1.1	8.7	4.1
16	8.3	7.9	16.0	16.2	2.4	1.2	1.2	7.0	1.3	9.0	4.8
18	8.6	8.0	16.3	16.5	2.7	1.4	1.4	7.0	1.5	9.3	5.5
20	8.9	8.1	16.6	16.9	3.1	1.6	1.6	7.0	1.7	9.6	6.2
22	9.2	8.2	17.0	17.4	3.6	1.8	1.8	7.0	2.0	10.0	7.0
24	9.5	8.3	17.3	17.8	4.0	1.9	1.9	7.0	2.2	10.3	7.8
26	9.9	8.4	17.7	18.3	4.5	2.1	2.1	7.0	2.5	10.7	8.6
28	10.3	8.5	18.2	18.9	5.0	2.3	2.3	7.0	2.8	11.2	9.5
30	10.8	8.7	18.7	19.5	5.6	2.5	2.5	7.0	3.1	11.7	10.4
32	11.3	8.8	19.2	20.1	6.2	2.7	2.7	7.0	3.4	12.2	11.3
34	11.8	9.0	19.7	20.8	6.9	2.9	2.9	7.0	3.8	12.7	12.3
36	12.4	9.2	20.3	21.6	7.6	3.1	3.1	7.0	4.2	13.3	13.4
38	13.1	9.3	21.0	22.5	8.4	3.3	3.3	7.0	4.7	14.0	14.5
40	13.9	9.5	21.7	23.4	9.3	3.5	3.5	7.0	5.2	14.7	15.6
42	14.7	9.7	22.6	24.5	10.3	3.8	3.8	7.0	5.7	15.6	16.9
44	15.7	9.9	23.5	25.7	11.4	4.0	4.0	7.0	6.3	16.5	18.2
46	16.9	10.2	24.6	27.0	12.7	4.3	4.3	7.0	7.0	17.6	19.7
48	18.2	10.4	25.8	28.6	14.2	4.5	4.5	7.0	7.9	18.8	21.2
50	19.8	10.7	27.3	30.5	15.9	4.8	4.8	7.0	8.8	20.3	23.0
52	21.7	11.0	29.0	32.7	18.0	5.1	5.1	7.0	10.0	22.0	24.8
54	24.0	11.3	31.1	35.4	20.6	5.4	5.4	7.0	11.4	24.1	26.9
56	27.0	11.7	33.8	38.7	23.8	5.7	5.7	7.0	13.2	26.8	29.3
58	31.1	12.1	37.4	43.2	28.1	6.1	6.1	7.0	15.6	30.4	32.0
60	36.9	12.6	42.4	49.5	34.2	6.5	6.5	7.0	19.0	35.4	35.2
62	46.1	13.2	50.5	59.4	43.8	7.0	7.0	7.0	24.3	43.5	39.3
64	64.7	14.0	66.3	78.7	62.9	7.6	7.6	7.0	34.9	59.3	44.7
66	141.6	15.4	131.0	157.0	140.6	8.5	8.5	7.0	78.0	124.0	54.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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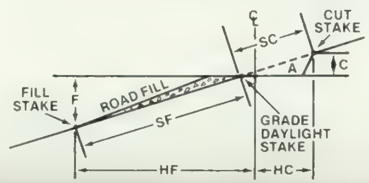
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



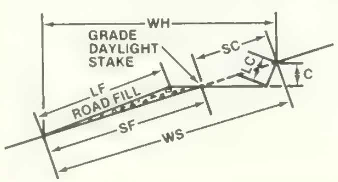
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 14 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.6	7.7	15.2	15.3	1.4	.8	.8	7.1	.8	8.1	2.9
12	7.8	7.8	15.5	15.6	1.7	.9	.9	7.1	.9	8.4	3.5
14	8.1	7.9	15.8	15.9	2.0	1.1	1.1	7.1	1.1	8.7	4.2
16	8.3	8.0	16.1	16.3	2.4	1.3	1.3	7.1	1.3	9.0	4.9
18	8.6	8.1	16.4	16.7	2.8	1.4	1.4	7.1	1.5	9.3	5.6
20	8.9	8.2	16.8	17.1	3.2	1.6	1.6	7.2	1.8	9.6	6.3
22	9.3	8.3	17.2	17.6	3.6	1.8	1.8	7.2	2.0	10.0	7.1
24	9.6	8.4	17.6	18.1	4.0	2.0	2.0	7.2	2.2	10.4	7.9
26	10.0	8.6	18.0	18.6	4.5	2.2	2.2	7.2	2.5	10.8	8.7
28	10.4	8.7	18.5	19.2	5.1	2.4	2.4	7.2	2.8	11.2	9.6
30	10.9	8.9	18.9	19.8	5.6	2.6	2.6	7.3	3.1	11.7	10.6
32	11.4	9.1	19.5	20.5	6.3	2.8	2.8	7.3	3.5	12.2	11.5
34	12.0	9.2	20.1	21.2	6.9	3.0	3.0	7.3	3.9	12.8	12.6
36	12.6	9.4	20.7	22.0	7.7	3.2	3.2	7.3	4.3	13.4	13.7
38	13.3	9.6	21.4	22.9	8.5	3.4	3.4	7.3	4.7	14.1	14.8
40	14.1	9.8	22.2	23.9	9.4	3.7	3.7	7.4	5.2	14.8	16.0
42	14.9	10.1	23.1	25.0	10.4	3.9	3.9	7.4	5.8	15.7	17.4
44	16.0	10.3	24.1	26.3	11.6	4.2	4.2	7.4	6.4	16.6	18.8
46	17.1	10.6	25.2	27.7	12.9	4.4	4.4	7.4	7.2	17.7	20.3
48	18.5	10.9	26.5	29.4	14.4	4.7	4.7	7.5	8.0	19.0	22.0
50	20.1	11.2	28.0	31.3	16.2	5.0	5.0	7.5	9.0	20.5	23.8
52	22.1	11.5	29.8	33.6	18.3	5.3	5.3	7.5	10.2	22.3	25.8
54	24.5	11.9	32.0	36.4	21.0	5.7	5.7	7.6	11.6	24.5	28.0
56	27.6	12.3	34.8	39.9	24.3	6.1	6.0	7.6	13.5	27.2	30.5
58	31.8	12.8	38.5	44.6	28.7	6.5	6.4	7.6	15.9	30.9	33.5
60	37.7	13.4	43.8	51.1	35.0	6.9	6.9	7.7	19.4	36.1	37.0
62	47.3	14.0	52.2	61.4	45.0	7.4	7.4	7.7	24.9	44.4	41.3
64	66.5	14.9	68.6	81.4	64.6	8.1	8.0	7.8	35.9	60.8	47.3
66	146.1	16.4	135.6	162.5	145.1	9.1	9.0	7.9	80.5	127.7	57.7

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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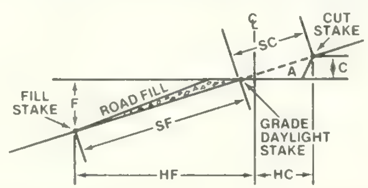
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

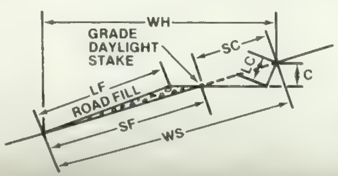
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 14 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.7	7.8	15.3	15.4	1.4	.8	.8	7.2	.8	8.1	2.9
12	7.9	7.9	15.6	15.8	1.7	1.0	.9	7.2	.9	8.4	3.6
14	8.1	8.0	16.0	16.1	2.0	1.1	1.1	7.3	1.1	8.7	4.2
16	8.4	8.1	16.3	16.5	2.4	1.3	1.3	7.3	1.3	9.0	4.9
18	8.7	8.2	16.7	16.9	2.8	1.5	1.5	7.4	1.5	9.3	5.7
20	9.0	8.4	17.1	17.4	3.2	1.7	1.6	7.4	1.8	9.7	6.4
22	9.4	8.5	17.5	17.9	3.6	1.9	1.8	7.5	2.0	10.0	7.2
24	9.7	8.7	17.9	18.4	4.1	2.1	2.0	7.5	2.3	10.4	8.1
26	10.1	8.9	18.4	19.0	4.6	2.3	2.2	7.6	2.5	10.8	9.0
28	10.6	9.0	18.9	19.6	5.1	2.5	2.4	7.6	2.8	11.3	9.9
30	11.0	9.2	19.4	20.3	5.7	2.7	2.7	7.7	3.2	11.8	10.9
32	11.6	9.4	20.0	21.0	6.4	3.0	2.9	7.7	3.5	12.3	11.9
34	12.2	9.7	20.6	21.8	7.1	3.2	3.1	7.8	3.9	12.9	13.0
36	12.8	9.9	21.3	22.7	7.8	3.4	3.3	7.8	4.3	13.5	14.1
38	13.5	10.1	22.1	23.7	8.7	3.7	3.6	7.9	4.8	14.2	15.4
40	14.3	10.4	23.0	24.7	9.6	4.0	3.9	8.0	5.3	15.0	16.7
42	15.3	10.7	23.9	25.9	10.7	4.3	4.1	8.0	5.9	15.9	18.1
44	16.3	10.9	25.0	27.3	11.9	4.5	4.4	8.1	6.6	16.9	19.7
46	17.5	11.3	26.2	28.8	13.2	4.9	4.7	8.2	7.3	18.0	21.3
48	19.0	11.6	27.6	30.6	14.8	5.2	5.0	8.3	8.2	19.3	23.1
50	20.7	12.0	29.2	32.7	16.7	5.5	5.4	8.3	9.2	20.9	25.1
52	22.7	12.4	31.2	35.1	18.9	5.9	5.7	8.4	10.5	22.7	27.3
54	25.3	12.8	33.5	38.1	21.6	6.3	6.1	8.5	12.0	25.0	29.8
56	28.5	13.3	36.5	41.9	25.1	6.7	6.5	8.6	13.9	27.9	32.7
58	32.9	13.9	40.5	46.8	29.8	7.2	7.0	8.7	16.5	31.8	36.0
60	39.2	14.6	46.1	53.8	36.4	7.7	7.5	8.9	20.2	37.3	39.9
62	49.3	15.4	55.0	64.8	46.9	8.4	8.1	9.0	26.0	46.0	44.9
64	69.6	16.5	72.5	86.1	67.6	9.2	8.9	9.2	37.5	63.3	51.7
66	153.7	18.2	143.5	172.0	152.7	10.4	10.1	9.5	84.7	134.0	63.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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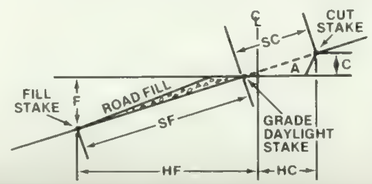
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



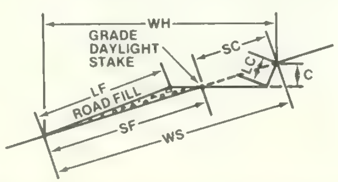
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 14 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.7	7.9	15.5	15.6	1.4	.9	.8	7.4	.8	8.2	2.9
12	8.0	8.1	15.9	16.0	1.7	1.1	1.0	7.5	.9	8.4	3.6
14	8.2	8.2	16.3	16.4	2.1	1.3	1.1	7.6	1.1	8.7	4.3
16	8.5	8.4	16.7	16.9	2.4	1.5	1.3	7.7	1.3	9.0	5.0
18	8.8	8.6	17.1	17.4	2.8	1.7	1.5	7.8	1.6	9.3	5.8
20	9.1	8.7	17.5	17.9	3.2	1.9	1.7	7.9	1.8	9.7	6.6
22	9.5	8.9	18.0	18.5	3.7	2.1	1.9	8.0	2.0	10.1	7.5
24	9.9	9.2	18.5	19.1	4.2	2.4	2.1	8.1	2.3	10.5	8.4
26	10.3	9.4	19.1	19.7	4.7	2.6	2.4	8.2	2.6	10.9	9.3
28	10.8	9.6	19.7	20.4	5.3	2.9	2.6	8.3	2.9	11.4	10.3
30	11.3	9.9	20.3	21.2	5.9	3.2	2.8	8.4	3.3	11.9	11.4
32	11.9	10.1	21.0	22.0	6.5	3.5	3.1	8.5	3.6	12.4	12.5
34	12.5	10.4	21.7	22.9	7.3	3.8	3.4	8.7	4.0	13.0	13.8
36	13.2	10.7	22.5	23.9	8.1	4.1	3.6	8.8	4.5	13.7	15.1
38	14.0	11.1	23.4	25.1	9.0	4.4	3.9	9.0	5.0	14.5	16.5
40	14.9	11.4	24.4	26.3	10.0	4.7	4.2	9.1	5.5	15.3	18.0
42	15.9	11.8	25.5	27.7	11.1	5.1	4.6	9.3	6.1	16.2	19.6
44	17.0	12.2	26.7	29.2	12.4	5.5	4.9	9.5	6.9	17.3	21.4
46	18.3	12.6	28.1	31.0	13.8	5.9	5.3	9.6	7.7	18.5	23.3
48	19.9	13.1	29.8	33.0	15.5	6.3	5.7	9.8	8.6	19.9	25.4
50	21.7	13.6	31.6	35.4	17.5	6.8	6.1	10.0	9.7	21.6	27.8
52	24.0	14.2	33.9	38.2	20.0	7.3	6.5	10.3	11.1	23.6	30.5
54	26.8	14.8	36.6	41.6	22.9	7.9	7.0	10.5	12.7	26.1	33.5
56	30.4	15.5	40.1	45.9	26.8	8.5	7.6	10.8	14.8	29.3	37.0
58	35.2	16.3	44.6	51.6	31.9	9.2	8.2	11.1	17.7	33.5	41.2
60	42.2	17.3	51.0	59.5	39.1	9.9	8.9	11.4	21.7	39.6	46.2
62	53.4	18.5	61.1	71.9	50.7	10.9	9.7	11.9	28.1	49.2	52.6
64	75.9	20.0	80.8	95.9	73.8	12.0	10.8	12.4	40.9	68.4	61.6
66	169.8	22.5	160.5	192.3	168.6	13.9	12.4	13.2	93.5	147.3	78.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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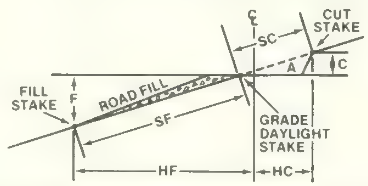
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

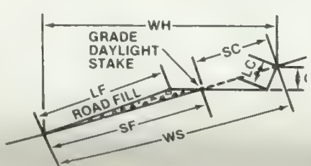
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 14 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.8	8.1	15.8	15.8	1.4	1.0	.8	7.6	.8	8.2	3.0
12	8.0	8.3	16.2	16.3	1.7	1.2	1.0	7.7	1.0	8.4	3.7
14	8.3	8.5	16.6	16.8	2.1	1.5	1.2	7.9	1.2	8.7	4.4
16	8.6	8.7	17.1	17.3	2.5	1.7	1.4	8.0	1.4	9.0	5.2
18	8.9	8.9	17.6	17.8	2.9	2.0	1.6	8.2	1.6	9.4	6.0
20	9.3	9.1	18.1	18.4	3.3	2.2	1.8	8.3	1.8	9.7	6.8
22	9.7	9.4	18.6	19.1	3.7	2.5	2.0	8.5	2.1	10.1	7.7
24	10.1	9.7	19.2	19.8	4.2	2.8	2.3	8.7	2.4	10.5	8.7
26	10.6	10.0	19.9	20.5	4.8	3.1	2.5	8.9	2.7	11.0	9.7
28	11.1	10.3	20.6	21.3	5.4	3.5	2.8	9.1	3.0	11.5	10.8
30	11.6	10.6	21.3	22.2	6.0	3.8	3.1	9.3	3.3	12.0	12.0
32	12.2	11.0	22.1	23.2	6.7	4.2	3.3	9.5	3.7	12.6	13.3
34	12.9	11.4	23.0	24.3	7.5	4.6	3.7	9.7	4.2	13.2	14.6
36	13.7	11.8	23.9	25.4	8.3	5.0	4.0	10.0	4.6	13.9	16.1
38	14.5	12.2	25.0	26.7	9.3	5.4	4.3	10.3	5.2	14.7	17.7
40	15.5	12.7	26.2	28.2	10.4	5.9	4.7	10.5	5.7	15.6	19.4
42	16.6	13.2	27.5	29.8	11.6	6.4	5.1	10.8	6.4	16.6	21.4
44	17.8	13.8	28.9	31.6	12.9	6.9	5.5	11.2	7.2	17.8	23.4
46	19.3	14.4	30.6	33.7	14.5	7.5	6.0	11.5	8.1	19.1	25.8
48	21.0	15.1	32.5	36.1	16.4	8.2	6.5	11.9	9.1	20.6	28.4
50	23.1	15.8	34.8	38.9	18.6	8.8	7.1	12.3	10.3	22.5	31.3
52	25.6	16.6	37.4	42.2	21.3	9.6	7.7	12.8	11.8	24.7	34.6
54	28.7	17.6	40.7	46.3	24.6	10.4	8.4	13.3	13.6	27.4	38.4
56	32.7	18.6	44.8	51.4	28.8	11.4	9.1	13.8	16.0	31.0	43.0
58	38.2	19.9	50.2	58.0	34.5	12.5	10.0	14.5	19.2	35.7	48.4
60	46.1	21.3	57.8	67.4	42.7	13.7	11.0	15.2	23.7	42.6	55.1
62	58.9	23.1	69.6	81.9	55.9	15.2	12.2	16.1	31.0	53.5	63.9
64	84.6	25.5	92.7	110.1	82.2	17.2	13.7	17.3	45.6	75.4	76.5
66	192.6	29.4	185.3	222.0	191.3	20.2	16.2	19.1	106.1	166.2	100.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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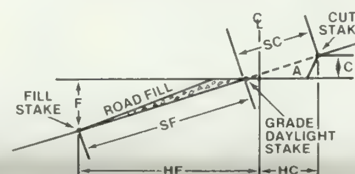
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

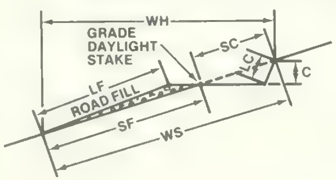
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 14 FEET

CUT SLOPE = 1.0 TO 1

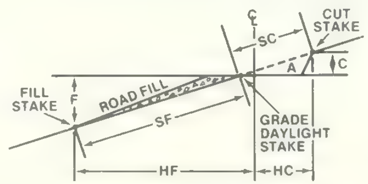
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.8	8.2	16.0	16.1	1.4	1.2	.8	7.8	.8	8.2	3.0
12	8.1	8.5	16.5	16.6	1.7	1.4	1.0	8.0	1.0	8.4	3.7
14	8.4	8.7	17.0	17.1	2.1	1.7	1.2	8.2	1.2	8.7	4.5
16	8.7	9.0	17.5	17.7	2.5	2.0	1.4	8.4	1.4	9.1	5.3
18	9.1	9.3	18.1	18.3	2.9	2.3	1.6	8.6	1.6	9.4	6.2
20	9.4	9.6	18.7	19.0	3.3	2.7	1.9	8.9	1.9	9.8	7.1
22	9.9	9.9	19.3	19.8	3.8	3.0	2.1	9.1	2.1	10.2	8.0
24	10.3	10.3	20.0	20.6	4.3	3.4	2.4	9.4	2.4	10.6	9.1
26	10.8	10.6	20.8	21.4	4.9	3.8	2.7	9.7	2.7	11.1	10.2
28	11.3	11.0	21.6	22.4	5.5	4.2	3.0	10.0	3.1	11.6	11.4
30	12.0	11.5	22.5	23.4	6.2	4.7	3.3	10.3	3.4	12.2	12.7
32	12.6	12.0	23.4	24.6	6.9	5.2	3.6	10.6	3.8	12.8	14.1
34	13.4	12.5	24.5	25.8	7.8	5.7	4.0	11.0	4.3	13.5	15.7
36	14.2	13.0	25.6	27.2	8.7	6.3	4.4	11.4	4.8	14.2	17.4
38	15.1	13.7	26.9	28.8	9.7	6.9	4.9	11.9	5.4	15.1	19.2
40	16.2	14.3	28.3	30.5	10.8	7.5	5.3	12.3	6.0	16.0	21.3
42	17.4	15.1	29.9	32.5	12.1	8.3	5.8	12.8	6.7	17.1	23.5
44	18.8	15.9	31.8	34.7	13.7	9.1	6.4	13.4	7.6	18.4	26.1
46	20.4	16.8	33.8	37.2	15.4	9.9	7.0	14.0	8.5	19.8	28.9
48	22.4	17.8	36.2	40.2	17.5	10.9	7.7	14.7	9.7	21.5	32.2
50	24.7	19.0	39.1	43.7	19.9	12.0	8.5	15.5	11.1	23.6	35.9
52	27.6	20.2	42.4	47.8	22.9	13.2	9.3	16.3	12.7	26.1	40.2
54	31.2	21.7	46.5	52.9	26.7	14.6	10.3	17.3	14.8	29.2	45.4
56	35.8	23.4	51.7	59.3	31.6	16.2	11.5	18.5	17.5	33.3	51.5
58	42.2	25.5	58.5	67.7	38.2	18.1	12.8	19.8	21.2	38.8	59.1
60	51.5	27.9	68.1	79.5	47.8	20.3	14.4	21.4	26.5	46.8	68.9
62	66.7	31.1	83.1	97.8	63.4	23.1	16.4	23.4	35.2	59.7	82.1
64	97.7	35.3	112.0	133.0	94.9	26.9	19.0	26.0	52.7	86.0	101.9
66	229.0	42.6	226.7	271.6	227.4	33.2	23.5	30.5	126.2	196.2	141.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

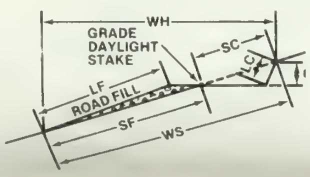
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 14 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	7.9	8.6	16.5	16.6	1.4	1.5	.9	8.3	.8	8.2	3.1
12	8.2	8.9	17.1	17.2	1.8	1.9	1.1	8.6	1.0	8.5	3.9
14	8.6	9.3	17.7	17.9	2.1	2.3	1.3	8.9	1.2	8.8	4.7
16	8.9	9.7	18.4	18.7	2.5	2.8	1.5	9.3	1.4	9.1	5.6
18	9.3	10.1	19.2	19.5	3.0	3.2	1.8	9.7	1.7	9.5	6.5
20	9.8	10.6	20.0	20.4	3.5	3.8	2.1	10.1	1.9	9.9	7.6
22	10.3	11.1	20.9	21.4	4.0	4.3	2.4	10.6	2.2	10.3	8.7
24	10.8	11.7	21.9	22.5	4.5	4.9	2.7	11.1	2.5	10.8	9.9
26	11.4	12.3	23.0	23.7	5.2	5.6	3.1	11.7	2.9	11.3	11.3
28	12.0	13.0	24.1	25.1	5.8	6.3	3.5	12.3	3.2	11.9	12.8
30	12.7	13.8	25.5	26.6	6.6	7.2	4.0	13.0	3.7	12.5	14.5
32	13.6	14.7	26.9	28.3	7.5	8.1	4.5	13.7	4.1	13.2	16.3
34	14.5	15.7	28.6	30.2	8.4	9.1	5.1	14.6	4.7	14.0	18.4
36	15.5	16.8	30.4	32.3	9.5	10.3	5.7	15.6	5.3	14.9	20.8
38	16.7	18.1	32.6	34.8	10.7	11.6	6.4	16.7	5.9	15.9	23.4
40	18.1	19.6	35.0	37.7	12.1	13.1	7.3	17.9	6.7	17.1	26.5
42	19.7	21.4	37.8	41.0	13.7	14.9	8.3	19.4	7.6	18.4	30.1
44	21.6	23.4	41.2	45.0	15.7	17.0	9.4	21.1	8.7	20.0	34.3
46	23.8	25.9	45.2	49.7	18.0	19.5	10.8	23.2	10.0	21.9	39.4
48	26.6	28.9	50.0	55.5	20.8	22.5	12.5	25.7	11.5	24.3	45.5
50	30.0	32.6	56.0	62.6	24.2	26.3	14.6	28.9	13.4	27.1	53.1
52	34.4	37.3	63.6	71.7	28.6	31.0	17.2	32.8	15.9	30.8	62.7
54	40.2	43.6	73.7	83.7	34.4	37.3	20.7	38.1	19.1	35.6	75.4
56	48.1	52.2	87.5	100.3	42.4	46.0	25.5	45.2	23.5	42.3	92.9
58	59.7	64.8	107.7	124.5	54.0	58.6	32.5	55.7	30.0	51.9	118.4
60	78.3	84.9	140.0	163.3	72.6	78.8	43.7	72.6	40.3	67.4	159.2
62	112.9	122.4	200.0	235.3	107.2	116.3	64.5	103.8	59.5	96.2	235.0
64	199.3	216.2	350.0	415.5	193.7	210.1	116.5	181.8	107.5	168.2	424.5
66	804.7	872.8	1400.0	1677.4	799.1	866.7	480.8	728.1	443.2	671.9	1751.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
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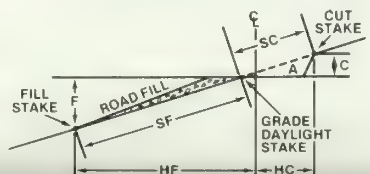
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

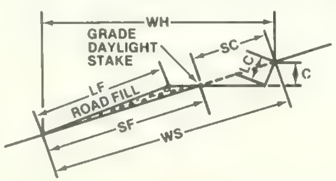
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SL

ROAD WIDTH = 15 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.1	8.1	16.2	16.3	1.5	.8	.8	7.5	.8	8.7	3.3
12	8.4	8.2	16.5	16.6	1.8	1.0	1.0	7.5	1.0	9.0	4.0
14	8.6	8.3	16.8	17.0	2.2	1.2	1.2	7.5	1.2	9.3	4.8
16	8.9	8.4	17.1	17.3	2.5	1.3	1.3	7.5	1.4	9.6	5.5
18	9.2	8.5	17.4	17.7	2.9	1.5	1.5	7.5	1.6	9.9	6.3
20	9.5	8.6	17.8	18.2	3.4	1.7	1.7	7.5	1.9	10.3	7.2
22	9.9	8.8	18.2	18.6	3.8	1.9	1.9	7.5	2.1	10.7	8.0
24	10.2	8.9	18.6	19.1	4.3	2.1	2.1	7.5	2.4	11.1	8.9
26	10.6	9.0	19.0	19.6	4.8	2.3	2.3	7.5	2.7	11.5	9.9
28	11.1	9.2	19.5	20.2	5.4	2.5	2.5	7.5	3.0	12.0	10.9
30	11.6	9.3	20.0	20.9	6.0	2.7	2.7	7.5	3.3	12.5	11.9
32	12.1	9.5	20.5	21.6	6.6	2.9	2.9	7.5	3.7	13.0	13.0
34	12.7	9.6	21.1	22.3	7.4	3.1	3.1	7.5	4.1	13.6	14.1
36	13.3	9.8	21.8	23.1	8.1	3.3	3.3	7.5	4.5	14.3	15.3
38	14.1	10.0	22.5	24.1	9.0	3.6	3.6	7.5	5.0	15.0	16.6
40	14.9	10.2	23.3	25.1	10.0	3.8	3.8	7.5	5.5	15.8	18.0
42	15.8	10.4	24.2	26.2	11.0	4.0	4.0	7.5	6.1	16.7	19.4
44	16.9	10.7	25.2	27.5	12.2	4.3	4.3	7.5	6.8	17.7	20.9
46	18.1	10.9	26.3	29.0	13.6	4.6	4.6	7.5	7.5	18.8	22.6
48	19.5	11.2	27.6	30.7	15.2	4.8	4.8	7.5	8.4	20.1	24.4
50	21.2	11.5	29.2	32.6	17.1	5.1	5.1	7.5	9.5	21.7	26.4
52	23.2	11.8	31.1	35.0	19.3	5.4	5.4	7.5	10.7	23.6	28.5
54	25.7	12.2	33.3	37.9	22.0	5.8	5.8	7.5	12.2	25.8	30.9
56	28.9	12.6	36.2	41.5	25.5	6.1	6.1	7.5	14.1	28.7	33.6
58	33.3	13.0	40.0	46.3	30.1	6.5	6.5	7.5	16.7	32.5	36.8
60	39.5	13.5	45.5	53.0	36.6	7.0	7.0	7.5	20.3	38.0	40.5
62	49.4	14.2	54.1	63.6	47.0	7.5	7.5	7.5	26.1	46.6	45.1
64	69.3	15.0	71.0	84.4	67.4	8.1	8.1	7.5	37.4	63.5	51.3
66	151.7	16.5	140.4	168.2	150.7	9.1	9.1	7.5	83.6	132.9	62.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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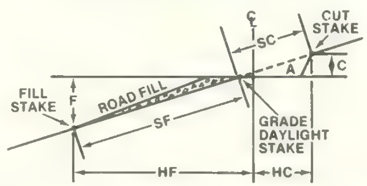
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

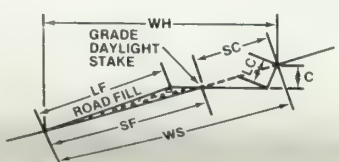
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 15 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.2	8.2	16.3	16.4	1.5	.8	.8	7.6	.8	8.7	3.3
12	8.4	8.3	16.6	16.7	1.8	1.0	1.0	7.6	1.0	9.0	4.0
14	8.7	8.4	16.9	17.1	2.2	1.2	1.2	7.6	1.2	9.3	4.8
16	8.9	8.5	17.3	17.5	2.5	1.4	1.3	7.6	1.4	9.6	5.6
18	9.2	8.6	17.6	17.9	3.0	1.5	1.5	7.7	1.6	10.0	6.4
20	9.6	8.8	18.0	18.3	3.4	1.7	1.7	7.7	1.9	10.3	7.3
22	9.9	8.9	18.4	18.8	3.8	1.9	1.9	7.7	2.1	10.7	8.1
24	10.3	9.0	18.8	19.4	4.3	2.1	2.1	7.7	2.4	11.1	9.1
26	10.7	9.2	19.3	19.9	4.9	2.3	2.3	7.7	2.7	11.5	10.0
28	11.2	9.4	19.8	20.5	5.4	2.5	2.5	7.8	3.0	12.0	11.1
30	11.7	9.5	20.3	21.2	6.0	2.8	2.7	7.8	3.4	12.5	12.1
32	12.2	9.7	20.9	21.9	6.7	3.0	3.0	7.8	3.7	13.1	13.2
34	12.8	9.9	21.5	22.7	7.4	3.2	3.2	7.8	4.1	13.7	14.4
36	13.5	10.1	22.2	23.6	8.2	3.4	3.4	7.8	4.6	14.4	15.7
38	14.2	10.3	22.9	24.6	9.1	3.7	3.7	7.9	5.1	15.1	17.0
40	15.1	10.6	23.8	25.6	10.1	3.9	3.9	7.9	5.6	15.9	18.4
42	16.0	10.8	24.7	26.8	11.2	4.2	4.2	7.9	6.2	16.8	19.9
44	17.1	11.1	25.8	28.2	12.4	4.5	4.5	7.9	6.9	17.8	21.6
46	18.3	11.3	27.0	29.7	13.8	4.8	4.7	8.0	7.7	19.0	23.3
48	19.8	11.7	28.4	31.5	15.5	5.1	5.0	8.0	8.6	20.4	25.2
50	21.5	12.0	30.0	33.5	17.4	5.4	5.4	8.0	9.6	21.9	27.3
52	23.6	12.3	31.9	36.0	19.7	5.7	5.7	8.1	10.9	23.9	29.6
54	26.2	12.8	34.3	39.0	22.5	6.1	6.1	8.1	12.5	26.2	32.2
56	29.6	13.2	37.3	42.8	26.0	6.5	6.5	8.1	14.4	29.2	35.1
58	34.0	13.7	41.3	47.7	30.8	6.9	6.9	8.2	17.1	33.1	38.4
60	40.4	14.3	46.9	54.7	37.5	7.4	7.4	8.2	20.8	38.7	42.4
62	50.7	15.0	55.9	65.8	48.2	8.0	7.9	8.3	26.7	47.6	47.4
64	71.3	16.0	73.5	87.3	69.3	8.7	8.6	8.4	38.4	65.1	54.3
66	156.5	17.6	145.3	174.1	155.4	9.7	9.7	8.5	86.2	136.8	66.3

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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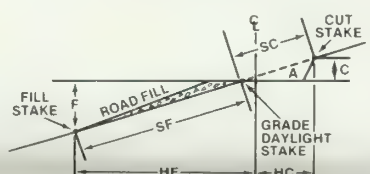
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



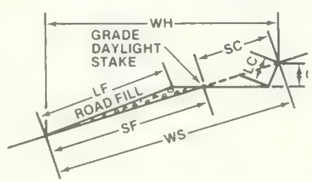
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 15 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.2	8.3	16.4	16.5	1.5	.9	.8	7.7	.8	8.7	3.3
12	8.5	8.4	16.8	16.9	1.8	1.0	1.0	7.8	1.0	9.0	4.1
14	8.7	8.6	17.1	17.3	2.2	1.2	1.2	7.8	1.2	9.3	4.9
16	9.0	8.7	17.5	17.7	2.6	1.4	1.4	7.8	1.4	9.6	5.7
18	9.3	8.8	17.9	18.2	3.0	1.6	1.6	7.9	1.7	10.0	6.5
20	9.7	9.0	18.3	18.6	3.4	1.8	1.8	7.9	1.9	10.3	7.4
22	10.0	9.1	18.7	19.2	3.9	2.0	2.0	8.0	2.2	10.7	8.3
24	10.4	9.3	19.2	19.7	4.4	2.2	2.2	8.0	2.4	11.1	9.3
26	10.8	9.5	19.7	20.3	4.9	2.5	2.4	8.1	2.7	11.6	10.3
28	11.3	9.7	20.2	21.0	5.5	2.7	2.6	8.2	3.1	12.1	11.3
30	11.8	9.9	20.8	21.7	6.1	2.9	2.8	8.2	3.4	12.6	12.5
32	12.4	10.1	21.4	22.5	6.8	3.2	3.1	8.3	3.8	13.2	13.6
34	13.0	10.3	22.1	23.4	7.6	3.4	3.3	8.3	4.2	13.8	14.9
36	13.7	10.6	22.9	24.3	8.4	3.7	3.6	8.4	4.6	14.5	16.2
38	14.5	10.8	23.7	25.3	9.3	4.0	3.9	8.5	5.2	15.2	17.7
40	15.4	11.1	24.6	26.5	10.3	4.3	4.1	8.5	5.7	16.1	19.2
42	16.4	11.4	25.6	27.8	11.4	4.6	4.4	8.6	6.3	17.0	20.8
44	17.5	11.7	26.8	29.2	12.7	4.9	4.7	8.7	7.0	18.1	22.6
46	18.8	12.1	28.0	30.9	14.2	5.2	5.0	8.8	7.9	19.3	24.5
48	20.3	12.4	29.5	32.8	15.9	5.5	5.4	8.8	8.8	20.7	26.6
50	22.1	12.8	31.3	35.0	17.9	5.9	5.7	8.9	9.9	22.4	28.8
52	24.3	13.3	33.4	37.6	20.2	6.3	6.1	9.0	11.2	24.3	31.4
54	27.1	13.8	35.9	40.8	23.2	6.7	6.5	9.1	12.9	26.8	34.2
56	30.6	14.3	39.2	44.9	26.9	7.2	7.0	9.2	14.9	29.9	37.5
58	35.3	14.9	43.4	50.2	31.9	7.7	7.5	9.4	17.7	34.0	41.3
60	42.0	15.6	49.4	57.7	39.0	8.3	8.0	9.5	21.6	39.9	45.8
62	52.9	16.5	59.0	69.4	50.2	9.0	8.7	9.7	27.9	49.3	51.6
64	74.6	17.7	77.7	92.2	72.5	9.8	9.5	9.9	40.2	67.8	59.4
66	164.7	19.6	153.8	184.3	163.6	11.1	10.8	10.2	90.7	143.6	73.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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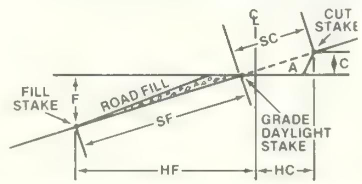
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

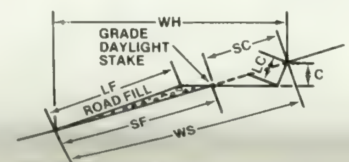
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 15 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.3	8.5	16.7	16.7	1.5	.9	.8	7.9	.8	8.7	3.4
12	8.5	8.6	17.0	17.2	1.8	1.2	1.0	8.0	1.0	9.0	4.1
14	8.8	8.8	17.4	17.6	2.2	1.4	1.2	8.1	1.2	9.3	4.9
16	9.1	9.0	17.9	18.1	2.6	1.6	1.4	8.2	1.4	9.7	5.8
18	9.4	9.2	18.3	18.6	3.0	1.8	1.6	8.3	1.7	10.0	6.7
20	9.8	9.4	18.8	19.2	3.5	2.1	1.8	8.4	1.9	10.4	7.6
22	10.2	9.6	19.3	19.8	3.9	2.3	2.1	8.5	2.2	10.8	8.6
24	10.6	9.8	19.9	20.4	4.5	2.6	2.3	8.6	2.5	11.2	9.6
26	11.1	10.1	20.4	21.1	5.0	2.8	2.5	8.8	2.8	11.7	10.7
28	11.6	10.3	21.1	21.9	5.6	3.1	2.8	8.9	3.1	12.2	11.9
30	12.1	10.6	21.7	22.7	6.3	3.4	3.0	9.0	3.5	12.7	13.1
32	12.7	10.9	22.5	23.6	7.0	3.7	3.3	9.2	3.9	13.3	14.4
34	13.4	11.2	23.3	24.6	7.8	4.0	3.6	9.3	4.3	14.0	15.8
36	14.2	11.5	24.1	25.7	8.6	4.4	3.9	9.4	4.8	14.7	17.3
38	15.0	11.9	25.1	26.8	9.6	4.7	4.2	9.6	5.3	15.5	18.9
40	15.9	12.2	26.1	28.2	10.7	5.1	4.5	9.8	5.9	16.4	20.6
42	17.0	12.6	27.3	29.6	11.9	5.5	4.9	9.9	6.6	17.4	22.5
44	18.2	13.1	28.6	31.3	13.2	5.9	5.3	10.1	7.3	18.5	24.5
46	19.7	13.5	30.1	33.2	14.8	6.3	5.7	10.3	8.2	19.8	26.8
48	21.3	14.0	31.9	35.4	16.6	6.8	6.1	10.5	9.2	21.3	29.2
50	23.3	14.6	33.9	37.9	18.8	7.3	6.5	10.8	10.4	23.1	31.9
52	25.7	15.2	36.3	40.9	21.4	7.8	7.0	11.0	11.9	25.3	35.0
54	28.7	15.9	39.2	44.6	24.6	8.4	7.5	11.3	13.6	28.0	38.5
56	32.6	16.6	42.9	49.2	28.7	9.1	8.1	11.6	15.9	31.4	42.5
58	37.7	17.5	47.8	55.2	34.1	9.8	8.8	11.9	18.9	35.9	47.3
60	45.2	18.5	54.7	63.7	41.9	10.7	9.5	12.3	23.3	42.4	53.0
62	57.2	19.8	65.4	77.0	54.4	11.6	10.4	12.7	30.2	52.7	60.4
64	81.4	21.4	86.6	102.8	79.1	12.9	11.5	13.3	43.9	73.3	70.7
66	181.9	24.1	172.0	206.0	180.7	14.8	13.3	14.1	100.2	157.8	89.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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LF = LENGTH OF FILL SLOPE
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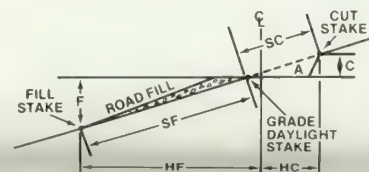
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



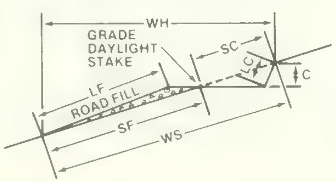
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 15 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.3	8.7	16.9	17.0	1.5	1.1	.9	8.1	.8	8.7	3.4
12	8.6	8.9	17.3	17.5	1.8	1.3	1.1	8.3	1.0	9.0	4.2
14	8.9	9.1	17.8	18.0	2.2	1.6	1.3	8.4	1.2	9.4	5.1
16	9.2	9.3	18.3	18.5	2.6	1.8	1.5	8.6	1.5	9.7	5.9
18	9.6	9.5	18.8	19.1	3.1	2.1	1.7	8.8	1.7	10.0	6.9
20	10.0	9.8	19.4	19.8	3.5	2.4	1.9	8.9	2.0	10.4	7.8
22	10.4	10.1	20.0	20.4	4.0	2.7	2.2	9.1	2.2	10.8	8.9
24	10.8	10.4	20.6	21.2	4.6	3.0	2.4	9.3	2.5	11.3	10.0
26	11.3	10.7	21.3	22.0	5.1	3.4	2.7	9.5	2.8	11.8	11.2
28	11.9	11.0	22.0	22.9	5.8	3.7	3.0	9.7	3.2	12.3	12.4
30	12.4	11.4	22.8	23.8	6.4	4.1	3.3	10.0	3.6	12.9	13.8
32	13.1	11.8	23.7	24.9	7.2	4.5	3.6	10.2	4.0	13.5	15.2
34	13.8	12.2	24.6	26.0	8.0	4.9	3.9	10.4	4.5	14.2	16.8
36	14.6	12.6	25.6	27.3	8.9	5.3	4.3	10.7	5.0	14.9	18.5
38	15.6	13.1	26.8	28.6	10.0	5.8	4.6	11.0	5.5	15.8	20.3
40	16.6	13.6	28.0	30.2	11.1	6.3	5.1	11.3	6.2	16.7	22.3
42	17.8	14.2	29.4	31.9	12.4	6.9	5.5	11.6	6.9	17.8	24.5
44	19.1	14.8	31.0	33.9	13.9	7.4	5.9	12.0	7.7	19.0	26.9
46	20.7	15.4	32.8	36.1	15.6	8.1	6.4	12.3	8.6	20.5	29.6
48	22.5	16.1	34.9	38.7	17.6	8.7	7.0	12.7	9.7	22.1	32.6
50	24.7	16.9	37.3	41.7	19.9	9.5	7.6	13.2	11.0	24.1	35.9
52	27.4	17.8	40.1	45.2	22.8	10.3	8.2	13.7	12.6	26.5	39.7
54	30.7	18.8	43.6	49.6	26.3	11.2	9.0	14.2	14.6	29.4	44.1
56	35.1	20.0	48.0	55.0	30.9	12.2	9.8	14.8	17.1	33.2	49.3
58	40.9	21.3	53.8	62.2	37.0	13.3	10.7	15.5	20.5	38.3	55.5
60	49.4	22.8	61.9	72.2	45.8	14.7	11.7	16.3	25.4	45.6	63.2
62	63.1	24.7	74.6	87.8	59.9	16.3	13.0	17.3	33.2	57.3	73.3
64	90.7	27.3	99.3	117.9	88.1	18.4	14.7	18.5	48.9	80.8	87.8
66	206.4	31.5	198.5	237.9	205.0	21.7	17.4	20.5	113.7	178.0	115.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
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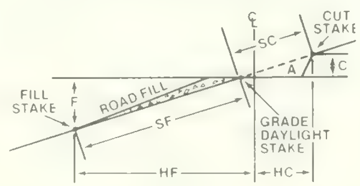
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

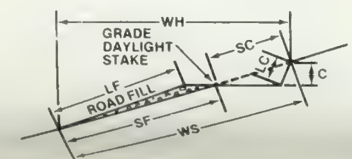
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 15 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.4	8.8	17.1	17.2	1.5	1.2	.9	8.4	.8	8.8	3.5
12	8.7	9.1	17.6	17.8	1.9	1.5	1.1	8.6	1.0	9.1	4.3
14	9.0	9.3	18.2	18.3	2.2	1.8	1.3	8.8	1.2	9.4	5.2
16	9.3	9.6	18.7	19.0	2.7	2.2	1.5	9.0	1.5	9.7	6.1
18	9.7	9.9	19.3	19.7	3.1	2.5	1.8	9.3	1.7	10.1	7.1
20	10.1	10.3	20.0	20.4	3.6	2.8	2.0	9.5	2.0	10.5	8.1
22	10.6	10.6	20.7	21.2	4.1	3.2	2.3	9.8	2.3	10.9	9.2
24	11.0	11.0	21.4	22.0	4.6	3.6	2.6	10.1	2.6	11.4	10.4
26	11.6	11.4	22.2	23.0	5.3	4.1	2.9	10.4	2.9	11.9	11.7
28	12.2	11.8	23.1	24.0	5.9	4.5	3.2	10.7	3.3	12.4	13.1
30	12.8	12.3	24.1	25.1	6.6	5.0	3.5	11.0	3.7	13.0	14.6
32	13.5	12.8	25.1	26.3	7.4	5.5	3.9	11.4	4.1	13.7	16.2
34	14.3	13.4	26.2	27.7	8.3	6.1	4.3	11.8	4.6	14.4	18.0
36	15.2	14.0	27.5	29.2	9.3	6.7	4.7	12.2	5.2	15.2	19.9
38	16.2	14.6	28.8	30.8	10.4	7.4	5.2	12.7	5.8	16.1	22.1
40	17.3	15.4	30.4	32.7	11.6	8.1	5.7	13.2	6.4	17.2	24.4
42	18.6	16.2	32.1	34.8	13.0	8.8	6.3	13.8	7.2	18.3	27.0
44	20.2	17.0	34.0	37.2	14.6	9.7	6.9	14.4	8.1	19.7	29.9
46	21.9	18.0	36.3	39.9	16.5	10.6	7.5	15.0	9.2	21.2	33.2
48	24.0	19.1	38.8	43.1	18.7	11.7	8.3	15.8	10.4	23.1	36.9
50	26.5	20.3	41.8	46.8	21.3	12.8	9.1	16.6	11.8	25.3	41.2
52	29.5	21.7	45.4	51.2	24.6	14.1	10.0	17.5	13.6	27.9	46.2
54	33.4	23.3	49.8	56.7	28.6	15.6	11.1	18.6	15.9	31.3	52.1
56	38.4	25.1	55.4	63.5	33.8	17.4	12.3	19.8	18.8	35.6	59.1
58	45.2	27.3	62.7	72.5	40.9	19.4	13.7	21.2	22.7	41.5	67.9
60	55.2	29.9	73.0	85.1	51.2	21.8	15.4	22.9	28.4	50.1	79.1
62	71.5	33.3	89.0	104.8	67.9	24.8	17.5	25.0	37.7	64.0	94.2
64	104.7	37.8	120.0	142.5	101.7	28.8	20.4	27.9	56.4	92.1	117.0
66	245.4	45.6	242.9	291.0	243.7	35.6	25.1	32.6	135.2	210.2	162.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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WS = TOT. WIDTH DISTURB. SLOPE
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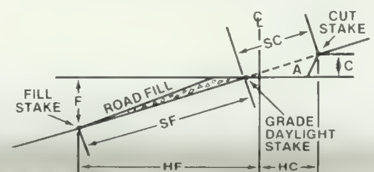
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

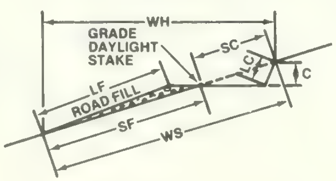
... 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 15 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.5	9.2	17.6	17.7	1.5	1.7	.9	8.9	.8	8.8	3.6
12	8.8	9.6	18.3	18.4	1.9	2.1	1.1	9.2	1.1	9.1	4.5
14	9.2	10.0	19.0	19.2	2.3	2.5	1.4	9.6	1.3	9.4	5.4
16	9.6	10.4	19.7	20.0	2.7	3.0	1.6	10.0	1.5	9.8	6.4
18	10.0	10.9	20.5	20.9	3.2	3.5	1.9	10.4	1.8	10.2	7.5
20	10.5	11.4	21.4	21.9	3.7	4.0	2.2	10.8	2.1	10.6	8.7
22	11.0	11.9	22.4	22.9	4.3	4.6	2.6	11.3	2.4	11.0	10.0
24	11.6	12.5	23.4	24.1	4.9	5.3	2.9	11.9	2.7	11.5	11.4
26	12.2	13.2	24.6	25.4	5.5	6.0	3.3	12.5	3.1	12.1	13.0
28	12.9	14.0	25.9	26.9	6.3	6.8	3.8	13.2	3.5	12.7	14.7
30	13.7	14.8	27.3	28.5	7.1	7.7	4.3	13.9	3.9	13.4	16.6
32	14.5	15.8	28.8	30.3	8.0	8.7	4.8	14.7	4.4	14.1	18.7
34	15.5	16.8	30.6	32.3	9.0	9.8	5.4	15.6	5.0	15.0	21.1
36	16.6	18.0	32.6	34.7	10.2	11.0	6.1	16.7	5.6	15.9	23.8
38	17.9	19.4	34.9	37.3	11.5	12.4	6.9	17.8	6.4	17.0	26.9
40	19.4	21.0	37.5	40.4	13.0	14.1	7.8	19.2	7.2	18.3	30.5
42	21.1	22.9	40.5	44.0	14.7	16.0	8.9	20.8	8.2	19.8	34.6
44	23.1	25.1	44.1	48.2	16.8	18.2	10.1	22.7	9.3	21.5	39.4
46	25.5	27.7	48.4	53.3	19.2	20.9	11.6	24.9	10.7	23.5	45.2
48	28.5	30.9	53.6	59.4	22.2	24.1	13.4	27.6	12.3	26.0	52.2
50	32.2	34.9	60.0	67.1	25.9	28.1	15.6	30.9	14.4	29.1	60.9
52	36.9	40.0	68.2	76.8	30.7	33.3	18.4	35.2	17.0	33.0	72.0
54	43.0	46.7	78.9	89.7	36.9	40.0	22.2	40.8	20.5	38.2	86.6
56	51.5	55.9	93.7	107.4	45.4	49.2	27.3	48.5	25.2	45.3	106.6
58	64.0	69.4	115.4	133.4	57.9	62.8	34.8	59.7	32.1	55.7	135.9
60	83.9	91.0	150.0	174.9	77.8	84.4	46.8	77.7	43.2	72.3	182.7
62	120.9	131.2	214.3	252.1	114.9	124.6	69.1	111.2	63.7	103.1	269.7
64	213.6	231.7	375.0	445.2	207.5	225.1	124.9	194.8	115.1	180.2	487.3
66	862.1	935.1	1500.0	1797.2	856.1	928.6	515.1	780.2	474.9	719.8	2010.1

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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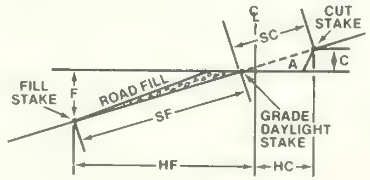
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

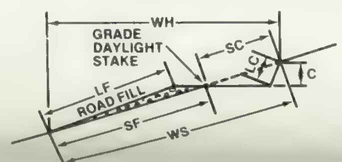
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 16 FEET

CUT SLOPE = VERTICAL

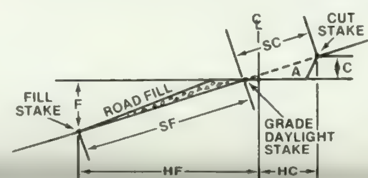
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.7	8.7	17.3	17.4	1.6	.9	.9	8.0	.9	9.3	3.7
12	8.9	8.8	17.6	17.7	1.9	1.0	1.0	8.0	1.1	9.6	4.6
14	9.2	8.9	17.9	18.1	2.3	1.2	1.2	8.0	1.3	9.9	5.4
16	9.5	9.0	18.3	18.5	2.7	1.4	1.4	8.0	1.5	10.3	6.3
18	9.8	9.1	18.6	18.9	3.1	1.6	1.6	8.0	1.7	10.6	7.2
20	10.2	9.2	19.0	19.4	3.6	1.8	1.8	8.0	2.0	11.0	8.2
22	10.5	9.3	19.4	19.9	4.1	2.0	2.0	8.0	2.3	11.4	9.1
24	10.9	9.5	19.8	20.4	4.6	2.2	2.2	8.0	2.5	11.8	10.2
26	11.3	9.6	20.3	21.0	5.1	2.4	2.4	8.0	2.9	12.3	11.2
28	11.8	9.8	20.8	21.6	5.7	2.6	2.6	8.0	3.2	12.8	12.4
30	12.3	9.9	21.3	22.3	6.4	2.9	2.9	8.0	3.5	13.3	13.5
32	12.9	10.1	21.9	23.0	7.1	3.1	3.1	8.0	3.9	13.9	14.8
34	13.5	10.3	22.5	23.8	7.9	3.3	3.3	8.0	4.4	14.5	16.1
36	14.2	10.5	23.2	24.7	8.7	3.5	3.5	8.0	4.8	15.2	17.4
38	15.0	10.7	24.0	25.7	9.6	3.8	3.8	8.0	5.3	16.0	18.9
40	15.9	10.9	24.8	26.8	10.6	4.0	4.0	8.0	5.9	16.8	20.4
42	16.9	11.1	25.8	28.0	11.8	4.3	4.3	8.0	6.5	17.8	22.1
44	18.0	11.4	26.9	29.3	13.1	4.6	4.6	8.0	7.2	18.9	23.8
46	19.3	11.6	28.1	30.9	14.5	4.9	4.9	8.0	8.1	20.1	25.7
48	20.8	11.9	29.5	32.7	16.2	5.2	5.2	8.0	9.0	21.5	27.8
50	22.6	12.2	31.1	34.8	18.2	5.5	5.5	8.0	10.1	23.1	30.0
52	24.7	12.6	33.1	37.3	20.6	5.8	5.8	8.0	11.4	25.1	32.4
54	27.4	13.0	35.6	40.4	23.5	6.2	6.2	8.0	13.0	27.6	35.2
56	30.9	13.4	38.6	44.3	27.2	6.5	6.5	8.0	15.1	30.6	38.3
58	35.5	13.9	42.7	49.4	32.1	7.0	7.0	8.0	17.8	34.7	41.8
60	42.1	14.4	48.5	56.6	39.1	7.4	7.4	8.0	21.7	40.5	46.0
62	52.7	15.1	57.7	67.9	50.1	8.0	8.0	8.0	27.8	49.7	51.3
64	73.9	16.0	75.8	90.0	71.8	8.6	8.6	8.0	39.9	67.8	58.4
66	161.8	17.6	149.7	179.4	160.7	9.7	9.7	8.0	89.1	141.7	70.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



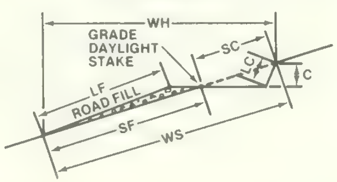
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 16 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.7	8.8	17.4	17.5	1.6	.9	.9	8.1	.9	9.3	3.8
12	9.0	8.9	17.7	17.8	1.9	1.1	1.1	8.1	1.1	9.6	4.6
14	9.2	9.0	18.0	18.2	2.3	1.3	1.2	8.1	1.3	9.9	5.5
16	9.5	9.1	18.4	18.6	2.7	1.4	1.4	8.1	1.5	10.3	6.4
18	9.9	9.2	18.8	19.1	3.1	1.6	1.6	8.2	1.7	10.6	7.3
20	10.2	9.4	19.2	19.6	3.6	1.8	1.8	8.2	2.0	11.0	8.3
22	10.6	9.5	19.6	20.1	4.1	2.1	2.0	8.2	2.3	11.4	9.3
24	11.0	9.7	20.1	20.6	4.6	2.3	2.3	8.2	2.6	11.8	10.3
26	11.4	9.8	20.6	21.2	5.2	2.5	2.5	8.2	2.9	12.3	11.4
28	11.9	10.0	21.1	21.9	5.8	2.7	2.7	8.3	3.2	12.8	12.6
30	12.4	10.2	21.7	22.6	6.4	2.9	2.9	8.3	3.6	13.4	13.8
32	13.0	10.4	22.3	23.4	7.2	3.2	3.2	8.3	4.0	14.0	15.1
34	13.7	10.6	22.9	24.2	7.9	3.4	3.4	8.3	4.4	14.6	16.4
36	14.4	10.8	23.7	25.2	8.8	3.7	3.7	8.4	4.9	15.3	17.8
38	15.2	11.0	24.5	26.2	9.7	3.9	3.9	8.4	5.4	16.1	19.4
40	16.1	11.3	25.4	27.3	10.8	4.2	4.2	8.4	6.0	17.0	21.0
42	17.1	11.5	26.4	28.6	11.9	4.5	4.5	8.4	6.6	17.9	22.7
44	18.2	11.8	27.5	30.0	13.2	4.8	4.8	8.5	7.3	19.0	24.5
46	19.6	12.1	28.8	31.7	14.7	5.1	5.1	8.5	8.2	20.3	26.5
48	21.1	12.4	30.3	33.6	16.5	5.4	5.4	8.5	9.1	21.7	28.7
50	23.0	12.8	32.0	35.8	18.5	5.7	5.7	8.6	10.3	23.4	31.1
52	25.2	13.2	34.1	38.4	21.0	6.1	6.1	8.6	11.6	25.4	33.7
54	28.0	13.6	36.6	41.6	24.0	6.5	6.5	8.6	13.3	27.9	36.6
56	31.5	14.1	39.8	45.6	27.8	6.9	6.9	8.7	15.4	31.1	39.9
58	36.3	14.6	44.1	50.9	32.8	7.4	7.3	8.7	18.2	35.3	43.7
60	43.1	15.3	50.1	58.4	40.0	7.9	7.9	8.8	22.2	41.3	48.3
62	54.1	16.0	59.6	70.1	51.4	8.5	8.4	8.8	28.5	50.8	54.0
64	76.0	17.0	78.4	93.1	73.9	9.2	9.2	8.9	41.0	69.5	61.7
66	167.0	18.7	155.0	185.7	165.8	10.4	10.3	9.0	92.0	145.9	75.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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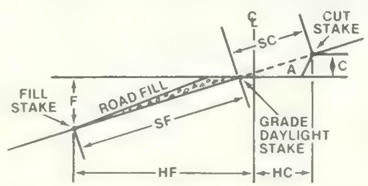
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

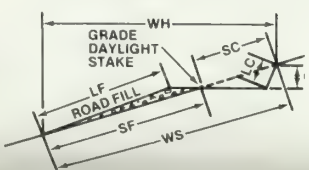
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 16 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.8	8.9	17.5	17.6	1.6	.9	.9	8.2	.9	9.3	3.8
12	9.0	9.0	17.9	18.0	1.9	1.1	1.1	8.3	1.1	9.6	4.6
14	9.3	9.1	18.3	18.4	2.3	1.3	1.3	8.3	1.3	9.9	5.5
16	9.6	9.3	18.6	18.9	2.7	1.5	1.5	8.4	1.5	10.3	6.4
18	9.9	9.4	19.1	19.4	3.2	1.7	1.7	8.4	1.8	10.6	7.4
20	10.3	9.6	19.5	19.9	3.6	1.9	1.9	8.5	2.0	11.0	8.4
22	10.7	9.8	20.0	20.4	4.1	2.2	2.1	8.5	2.3	11.4	9.4
24	11.1	9.9	20.5	21.0	4.7	2.4	2.3	8.6	2.6	11.9	10.5
26	11.6	10.1	21.0	21.7	5.2	2.6	2.6	8.6	2.9	12.4	11.7
28	12.1	10.3	21.6	22.4	5.9	2.9	2.8	8.7	3.3	12.9	12.9
30	12.6	10.6	22.2	23.2	6.5	3.1	3.0	8.8	3.6	13.4	14.2
32	13.2	10.8	22.9	24.0	7.3	3.4	3.3	8.8	4.0	14.0	15.5
34	13.9	11.0	23.6	24.9	8.1	3.7	3.6	8.9	4.5	14.7	17.0
36	14.6	11.3	24.4	25.9	8.9	3.9	3.8	9.0	5.0	15.4	18.5
38	15.5	11.6	25.3	27.0	9.9	4.2	4.1	9.0	5.5	16.2	20.1
40	16.4	11.9	26.2	28.3	11.0	4.5	4.4	9.1	6.1	17.1	21.8
42	17.5	12.2	27.3	29.6	12.2	4.9	4.7	9.2	6.8	18.1	23.7
44	18.7	12.5	28.5	31.2	13.5	5.2	5.0	9.3	7.5	19.3	25.7
46	20.1	12.9	29.9	32.9	15.1	5.5	5.4	9.3	8.4	20.6	27.8
48	21.7	13.3	31.5	35.0	16.9	5.9	5.7	9.4	9.4	22.1	30.2
50	23.6	13.7	33.4	37.3	19.0	6.3	6.1	9.5	10.6	23.8	32.8
52	26.0	14.2	35.6	40.1	21.6	6.7	6.5	9.6	12.0	26.0	35.7
54	28.9	14.7	38.3	43.6	24.7	7.2	7.0	9.7	13.7	28.6	39.0
56	32.6	15.3	41.8	47.9	28.7	7.7	7.5	9.9	15.9	31.9	42.7
58	37.6	15.9	46.3	53.5	34.0	8.2	8.0	10.0	18.9	36.3	47.0
60	44.8	16.7	52.7	61.5	41.6	8.8	8.6	10.1	23.1	42.6	52.2
62	56.4	17.6	62.9	74.0	53.6	9.6	9.3	10.3	29.7	52.6	58.7
64	79.5	18.8	82.9	98.4	77.3	10.5	10.1	10.5	42.9	72.3	67.6
66	175.7	20.9	164.0	196.5	174.5	11.8	11.5	10.9	96.8	153.2	83.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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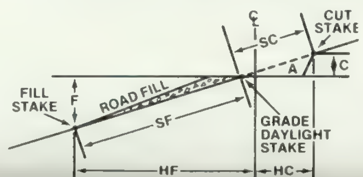
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



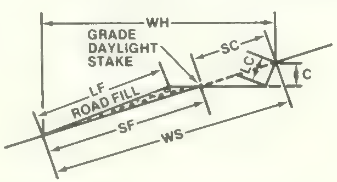
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.8	9.0	17.8	17.9	1.6	1.0	.9	8.4	.9	9.3	3.8
12	9.1	9.2	18.2	18.3	2.0	1.2	1.1	8.5	1.1	9.6	4.7
14	9.4	9.4	18.6	18.8	2.3	1.5	1.3	8.7	1.3	10.0	5.6
16	9.7	9.6	19.1	19.3	2.8	1.7	1.5	8.8	1.5	10.3	6.6
18	10.1	9.8	19.5	19.9	3.2	1.9	1.7	8.9	1.8	10.7	7.6
20	10.5	10.0	20.1	20.5	3.7	2.2	2.0	9.0	2.1	11.1	8.7
22	10.9	10.2	20.6	21.1	4.2	2.5	2.2	9.1	2.3	11.5	9.8
24	11.3	10.5	21.2	21.8	4.8	2.7	2.4	9.2	2.6	12.0	10.9
26	11.8	10.7	21.8	22.5	5.4	3.0	2.7	9.3	3.0	12.5	12.2
28	12.3	11.0	22.5	23.3	6.0	3.3	3.0	9.5	3.3	13.0	13.5
30	12.9	11.3	23.2	24.2	6.7	3.6	3.2	9.6	3.7	13.6	14.9
32	13.6	11.6	24.0	25.2	7.5	3.9	3.5	9.8	4.1	14.2	16.4
34	14.3	11.9	24.8	26.2	8.3	4.3	3.8	9.9	4.6	14.9	18.0
36	15.1	12.3	25.7	27.4	9.2	4.6	4.2	10.1	5.1	15.7	19.7
38	16.0	12.6	26.8	28.6	10.2	5.0	4.5	10.2	5.7	16.5	21.5
40	17.0	13.0	27.9	30.0	11.4	5.4	4.8	10.4	6.3	17.5	23.5
42	18.1	13.5	29.1	31.6	12.7	5.8	5.2	10.6	7.0	18.5	25.6
44	19.5	13.9	30.6	33.4	14.1	6.3	5.6	10.8	7.8	19.8	27.9
46	21.0	14.4	32.2	35.4	15.8	6.7	6.0	11.0	8.8	21.1	30.4
48	22.7	15.0	34.0	37.7	17.7	7.2	6.5	11.2	9.8	22.8	33.2
50	24.9	15.6	36.2	40.4	20.0	7.8	7.0	11.5	11.1	24.7	36.3
52	27.4	16.2	38.7	43.6	22.8	8.4	7.5	11.7	12.7	27.0	39.8
54	30.6	16.9	41.8	47.6	26.2	9.0	8.0	12.0	14.5	29.8	43.8
56	34.7	17.8	45.8	52.5	30.6	9.7	8.7	12.3	17.0	33.4	48.4
58	40.3	18.7	51.0	58.9	36.4	10.5	9.4	12.7	20.2	38.3	53.8
60	48.2	19.8	58.3	68.0	44.7	11.4	10.2	13.1	24.8	45.2	60.3
62	61.0	21.1	69.8	82.1	58.0	12.4	11.1	13.6	32.2	56.3	68.7
64	86.8	22.8	92.3	109.6	84.3	13.8	12.3	14.2	46.8	78.2	80.5
66	194.1	25.7	183.4	219.8	192.7	15.8	14.2	15.1	106.9	168.4	101.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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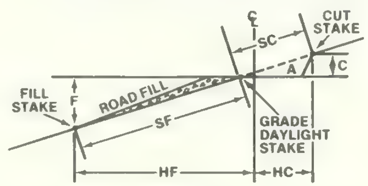
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

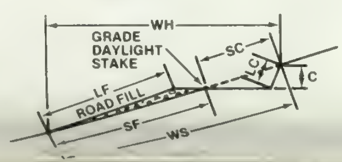
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 16 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.9	9.2	18.0	18.1	1.6	1.1	.9	8.7	.9	9.3	3.9
12	9.2	9.4	18.5	18.6	2.0	1.4	1.1	8.8	1.1	9.6	4.8
14	9.5	9.7	19.0	19.2	2.4	1.7	1.3	9.0	1.3	10.0	5.7
16	9.8	9.9	19.5	19.8	2.8	2.0	1.6	9.2	1.6	10.3	6.8
18	10.2	10.2	20.1	20.4	3.3	2.3	1.8	9.4	1.8	10.7	7.8
20	10.6	10.5	20.7	21.1	3.8	2.6	2.0	9.5	2.1	11.1	8.9
22	11.1	10.7	21.3	21.8	4.3	2.9	2.3	9.7	2.4	11.6	10.1
24	11.5	11.1	22.0	22.6	4.9	3.2	2.6	9.9	2.7	12.0	11.4
26	12.1	11.4	22.7	23.5	5.5	3.6	2.9	10.2	3.0	12.6	12.7
28	12.6	11.7	23.5	24.4	6.1	4.0	3.2	10.4	3.4	13.1	14.2
30	13.3	12.1	24.3	25.4	6.9	4.4	3.5	10.6	3.8	13.7	15.7
32	14.0	12.5	25.3	26.5	7.7	4.8	3.8	10.9	4.3	14.4	17.3
34	14.8	13.0	26.3	27.7	8.6	5.2	4.2	11.1	4.7	15.1	19.1
36	15.6	13.5	27.4	29.1	9.5	5.7	4.6	11.4	5.3	15.9	21.0
38	16.6	14.0	28.6	30.6	10.6	6.2	5.0	11.7	5.9	16.8	23.1
40	17.7	14.5	29.9	32.2	11.8	6.7	5.4	12.0	6.6	17.9	25.4
42	18.9	15.1	31.4	34.0	13.2	7.3	5.8	12.4	7.3	19.0	27.9
44	20.4	15.7	33.1	36.1	14.8	7.9	6.3	12.8	8.2	20.3	30.6
46	22.0	16.5	35.0	38.5	16.6	8.6	6.9	13.2	9.2	21.8	33.7
48	24.0	17.2	37.2	41.2	18.7	9.3	7.5	13.6	10.4	23.6	37.0
50	26.4	18.1	39.7	44.4	21.2	10.1	8.1	14.1	11.8	25.7	40.9
52	29.2	19.0	42.8	48.2	24.3	11.0	8.8	14.6	13.5	28.2	45.2
54	32.8	20.1	46.5	52.9	28.1	11.9	9.5	15.2	15.6	31.4	50.2
56	37.4	21.3	51.2	58.7	32.9	13.0	10.4	15.8	18.3	35.4	56.1
58	43.6	22.7	57.4	66.3	39.5	14.2	11.4	16.5	21.9	40.8	63.2
60	52.7	24.4	66.0	77.0	48.8	15.7	12.5	17.4	27.1	48.6	71.9
62	67.3	26.4	79.6	93.6	63.9	17.4	13.9	18.4	35.4	61.2	83.4
64	96.7	29.1	106.0	125.8	94.0	19.6	15.7	19.8	52.1	86.2	99.9
66	220.2	33.6	211.8	253.8	218.6	23.1	18.5	21.9	121.3	189.9	131.1

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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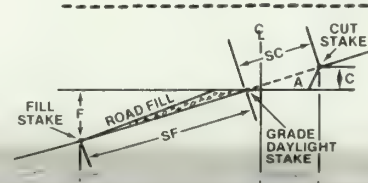
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



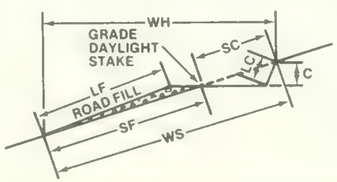
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 16 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	8.9	9.4	18.3	18.4	1.6	1.3	.9	8.9	.9	9.3	4.0
12	9.3	9.7	18.8	18.9	2.0	1.6	1.2	9.2	1.1	9.7	4.9
14	9.6	10.0	19.4	19.6	2.4	2.0	1.4	9.4	1.3	10.0	5.9
16	10.0	10.3	20.0	20.2	2.8	2.3	1.6	9.6	1.6	10.4	6.9
18	10.4	10.6	20.6	21.0	3.3	2.7	1.9	9.9	1.8	10.8	8.0
20	10.8	11.0	21.3	21.7	3.8	3.0	2.1	10.1	2.1	11.2	9.2
22	11.3	11.3	22.1	22.6	4.4	3.4	2.4	10.4	2.4	11.6	10.5
24	11.8	11.7	22.9	23.5	5.0	3.9	2.7	10.7	2.7	12.1	11.9
26	12.3	12.2	23.7	24.5	5.6	4.3	3.1	11.1	3.1	12.7	13.3
28	13.0	12.6	24.7	25.6	6.3	4.8	3.4	11.4	3.5	13.2	14.9
30	13.7	13.1	25.7	26.8	7.1	5.3	3.8	11.8	3.9	13.9	16.6
32	14.4	13.7	26.8	28.1	7.9	5.9	4.2	12.2	4.4	14.6	18.5
34	15.3	14.3	28.0	29.5	8.9	6.5	4.6	12.6	4.9	15.4	20.5
36	16.2	14.9	29.3	31.1	9.9	7.1	5.1	13.1	5.5	16.2	22.7
38	17.3	15.6	30.8	32.9	11.1	7.8	5.5	13.5	6.1	17.2	25.1
40	18.5	16.4	32.4	34.9	12.4	8.6	6.1	14.1	6.9	18.3	27.8
42	19.9	17.2	34.2	37.1	13.9	9.4	6.7	14.7	7.7	19.6	30.7
44	21.5	18.2	36.3	39.7	15.6	10.3	7.3	15.3	8.7	21.0	34.1
46	23.4	19.2	38.7	42.6	17.6	11.3	8.0	16.0	9.8	22.6	37.8
48	25.6	20.4	41.4	45.9	20.0	12.5	8.8	16.8	11.1	24.6	42.0
50	28.2	21.7	44.6	49.9	22.8	13.7	9.7	17.7	12.6	26.9	46.9
52	31.5	23.1	48.5	54.6	26.2	15.1	10.7	18.7	14.5	29.8	52.6
54	35.6	24.8	53.2	60.4	30.5	16.7	11.8	19.8	16.9	33.4	59.2
56	41.0	26.8	59.1	67.7	36.1	18.5	13.1	21.1	20.0	38.0	67.3
58	48.2	29.1	66.9	77.3	43.6	20.7	14.6	22.6	24.2	44.3	77.2
60	58.9	31.9	77.9	90.8	54.6	23.2	16.4	24.4	30.3	53.4	90.0
62	76.2	35.5	95.0	111.7	72.4	26.5	18.7	26.7	40.2	68.3	107.2
64	111.6	40.4	128.0	152.0	108.5	30.8	21.8	29.8	60.2	98.3	133.1
66	261.7	48.7	259.1	310.4	259.9	37.9	26.8	34.8	144.2	224.3	185.3

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
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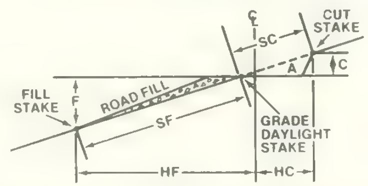
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

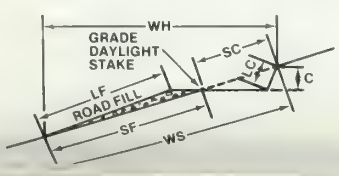
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 16 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.1	9.8	18.8	18.9	1.6	1.8	1.0	9.5	.9	9.4	4.1
12	9.4	10.2	19.5	19.7	2.0	2.2	1.2	9.8	1.1	9.7	5.1
14	9.8	10.6	20.3	20.5	2.5	2.7	1.5	10.2	1.4	10.0	6.1
16	10.2	11.1	21.1	21.3	2.9	3.2	1.8	10.6	1.6	10.4	7.3
18	10.7	11.6	21.9	22.3	3.4	3.7	2.1	11.1	1.9	10.8	8.5
20	11.2	12.1	22.9	23.3	4.0	4.3	2.4	11.6	2.2	11.3	9.9
22	11.7	12.7	23.9	24.5	4.5	4.9	2.7	12.1	2.5	11.8	11.4
24	12.3	13.4	25.0	25.7	5.2	5.6	3.1	12.7	2.9	12.3	13.0
26	13.0	14.1	26.2	27.1	5.9	6.4	3.5	13.3	3.3	12.9	14.8
28	13.7	14.9	27.6	28.6	6.7	7.2	4.0	14.0	3.7	13.6	16.7
30	14.6	15.8	29.1	30.4	7.5	8.2	4.5	14.8	4.2	14.3	18.9
32	15.5	16.8	30.8	32.3	8.5	9.2	5.1	15.7	4.7	15.1	21.3
34	16.5	17.9	32.7	34.5	9.6	10.4	5.8	16.7	5.3	16.0	24.0
36	17.7	19.2	34.8	37.0	10.8	11.7	6.5	17.8	6.0	17.0	27.1
38	19.1	20.7	37.2	39.8	12.2	13.3	7.4	19.0	6.8	18.2	30.6
40	20.7	22.4	40.0	43.1	13.8	15.0	8.3	20.5	7.7	19.5	34.7
42	22.5	24.4	43.2	46.9	15.7	17.0	9.4	22.2	8.7	21.1	39.3
44	24.7	26.8	47.1	51.4	17.9	19.4	10.8	24.2	9.9	22.9	44.8
46	27.3	29.6	51.6	56.8	20.5	22.3	12.4	26.5	11.4	25.1	51.4
48	30.4	33.0	57.1	63.4	23.7	25.7	14.3	29.4	13.2	27.7	59.4
50	34.3	37.2	64.0	71.6	27.7	30.0	16.6	33.0	15.4	31.0	69.3
52	39.3	42.7	72.7	82.0	32.7	35.5	19.7	37.5	18.1	35.2	81.9
54	45.9	49.8	84.2	95.7	39.3	42.7	23.7	43.5	21.8	40.7	98.5
56	55.0	59.6	100.0	114.6	48.4	52.5	29.1	51.7	26.9	48.3	121.3
58	68.3	74.0	123.1	142.3	61.7	67.0	37.1	63.7	34.2	59.4	154.6
60	89.5	97.1	160.0	186.6	83.0	90.0	49.9	82.9	46.1	77.1	207.9
62	129.0	139.9	228.6	268.9	122.6	132.9	73.7	118.6	68.0	110.0	306.9
64	227.8	247.1	400.0	474.9	221.4	240.1	133.2	207.8	122.8	192.2	554.4
66	919.6	997.5	1600.0	1917.1	913.2	990.5	549.4	832.2	506.6	767.8	2287.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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WH = TOT. WIDTH DISTURB. HOR.
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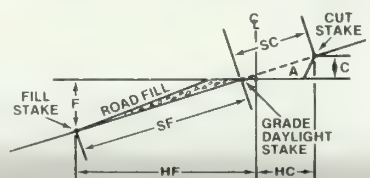
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

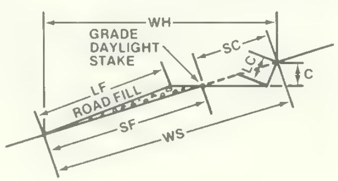
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 17 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.2	9.2	18.4	18.5	1.7	.9	.9	8.5	.9	9.9	4.2
12	9.5	9.3	18.7	18.8	2.0	1.1	1.1	8.5	1.1	10.2	5.2
14	9.8	9.4	19.0	19.2	2.4	1.3	1.3	8.5	1.4	10.5	6.1
16	10.1	9.5	19.4	19.6	2.9	1.5	1.5	8.5	1.6	10.9	7.1
18	10.4	9.7	19.8	20.1	3.3	1.7	1.7	8.5	1.8	11.3	8.1
20	10.8	9.8	20.2	20.6	3.8	1.9	1.9	8.5	2.1	11.7	9.2
22	11.2	9.9	20.6	21.1	4.3	2.1	2.1	8.5	2.4	12.1	10.3
24	11.6	10.1	21.1	21.7	4.9	2.3	2.3	8.5	2.7	12.6	11.5
26	12.1	10.2	21.6	22.3	5.5	2.6	2.6	8.5	3.0	13.1	12.7
28	12.6	10.4	22.1	22.9	6.1	2.8	2.8	8.5	3.4	13.6	14.0
30	13.1	10.5	22.6	23.6	6.8	3.0	3.0	8.5	3.8	14.1	15.3
32	13.7	10.7	23.3	24.4	7.5	3.3	3.3	8.5	4.2	14.8	16.7
34	14.4	10.9	23.9	25.3	8.3	3.5	3.5	8.5	4.6	15.4	18.1
36	15.1	11.1	24.7	26.2	9.2	3.8	3.8	8.5	5.1	16.2	19.7
38	15.9	11.3	25.5	27.3	10.2	4.0	4.0	8.5	5.7	17.0	21.3
40	16.9	11.6	26.4	28.4	11.3	4.3	4.3	8.5	6.3	17.9	23.1
42	17.9	11.8	27.4	29.7	12.5	4.6	4.6	8.5	6.9	18.9	24.9
44	19.1	12.1	28.5	31.2	13.9	4.9	4.9	8.5	7.7	20.0	26.9
46	20.5	12.4	29.8	32.8	15.4	5.2	5.2	8.5	8.6	21.3	29.0
48	22.1	12.7	31.3	34.8	17.2	5.5	5.5	8.5	9.6	22.8	31.3
50	24.0	13.0	33.1	37.0	19.3	5.8	5.8	8.5	10.7	24.6	33.8
52	26.3	13.4	35.2	39.7	21.9	6.2	6.2	8.5	12.1	26.7	36.6
54	29.1	13.8	37.8	42.9	25.0	6.5	6.5	8.5	13.9	29.3	39.7
56	32.8	14.2	41.0	47.0	28.9	7.0	7.0	8.5	16.0	32.5	43.2
58	37.7	14.7	45.4	52.5	34.1	7.4	7.4	8.5	18.9	36.9	47.2
60	44.8	15.3	51.5	60.1	41.5	7.9	7.9	8.5	23.0	43.0	52.0
62	56.0	16.1	61.3	72.1	53.2	8.5	8.5	8.5	29.5	52.8	57.9
64	78.6	17.0	80.5	95.6	76.3	9.2	9.2	8.5	42.3	72.0	65.9
66	171.9	18.6	159.1	190.6	170.7	10.3	10.3	8.5	94.7	150.6	79.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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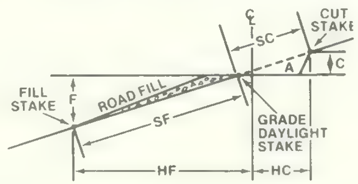
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

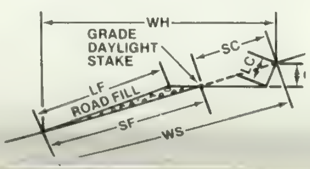
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 17 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.3	9.3	18.5	18.6	1.7	.9	.9	8.6	.9	9.9	4.2
12	9.5	9.4	18.8	19.0	2.0	1.1	1.1	8.6	1.1	10.2	5.2
14	9.8	9.5	19.2	19.4	2.5	1.3	1.3	8.6	1.4	10.5	6.2
16	10.1	9.7	19.6	19.8	2.9	1.5	1.5	8.7	1.6	10.9	7.2
18	10.5	9.8	20.0	20.3	3.3	1.7	1.7	8.7	1.9	11.3	8.2
20	10.8	9.9	20.4	20.8	3.8	2.0	1.9	8.7	2.1	11.7	9.3
22	11.2	10.1	20.8	21.3	4.4	2.2	2.2	8.7	2.4	12.1	10.5
24	11.7	10.3	21.3	21.9	4.9	2.4	2.4	8.7	2.7	12.6	11.6
26	12.1	10.4	21.8	22.6	5.5	2.6	2.6	8.8	3.1	13.1	12.9
28	12.7	10.6	22.4	23.3	6.2	2.9	2.9	8.8	3.4	13.6	14.2
30	13.2	10.8	23.0	24.0	6.8	3.1	3.1	8.8	3.8	14.2	15.6
32	13.8	11.0	23.7	24.8	7.6	3.4	3.4	8.8	4.2	14.8	17.0
34	14.5	11.2	24.4	25.7	8.4	3.6	3.6	8.9	4.7	15.5	18.5
36	15.3	11.5	25.2	26.7	9.3	3.9	3.9	8.9	5.2	16.3	20.1
38	16.1	11.7	26.0	27.8	10.3	4.2	4.2	8.9	5.7	17.1	21.8
40	17.1	12.0	27.0	29.0	11.4	4.5	4.4	8.9	6.3	18.0	23.7
42	18.2	12.2	28.0	30.4	12.7	4.8	4.7	9.0	7.0	19.0	25.6
44	19.4	12.5	29.2	31.9	14.1	5.1	5.0	9.0	7.8	20.2	27.7
46	20.8	12.9	30.6	33.7	15.7	5.4	5.4	9.0	8.7	21.5	29.9
48	22.4	13.2	32.1	35.7	17.5	5.7	5.7	9.1	9.7	23.1	32.4
50	24.4	13.6	34.0	38.0	19.7	6.1	6.1	9.1	10.9	24.9	35.1
52	26.8	14.0	36.2	40.8	22.3	6.5	6.5	9.1	12.4	27.0	38.0
54	29.7	14.5	38.9	44.2	25.5	6.9	6.9	9.2	14.1	29.7	41.3
56	33.5	15.0	42.3	48.5	29.5	7.3	7.3	9.2	16.4	33.1	45.0
58	38.6	15.5	46.8	54.1	34.9	7.8	7.8	9.3	19.3	37.5	49.4
60	45.8	16.2	53.2	62.0	42.5	8.4	8.3	9.3	23.6	43.9	54.5
62	57.5	17.0	63.3	74.5	54.6	9.0	9.0	9.4	30.3	53.9	60.9
64	80.8	18.1	83.3	98.9	78.5	9.8	9.8	9.5	43.5	73.8	69.7
66	177.4	19.9	164.7	197.3	176.2	11.0	11.0	9.6	97.7	155.1	85.1

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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WH = TOT. WIDTH DISTURB. HOR.
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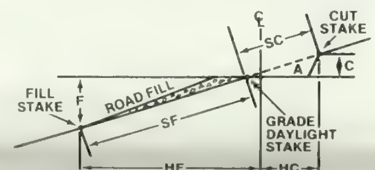
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

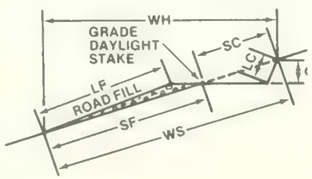
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 17 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.3	9.4	18.6	18.7	1.7	1.0	.9	8.7	.9	9.9	4.3
12	9.6	9.6	19.0	19.1	2.1	1.2	1.1	8.8	1.1	10.2	5.2
14	9.9	9.7	19.4	19.6	2.5	1.4	1.3	8.8	1.4	10.6	6.2
16	10.2	9.9	19.8	20.1	2.9	1.6	1.6	8.9	1.6	10.9	7.3
18	10.6	10.0	20.2	20.6	3.4	1.8	1.8	8.9	1.9	11.3	8.3
20	10.9	10.2	20.7	21.1	3.9	2.1	2.0	9.0	2.1	11.7	9.5
22	11.4	10.4	21.2	21.7	4.4	2.3	2.2	9.1	2.4	12.2	10.7
24	11.8	10.6	21.7	22.4	5.0	2.5	2.5	9.1	2.8	12.6	11.9
26	12.3	10.8	22.3	23.1	5.6	2.8	2.7	9.2	3.1	13.1	13.2
28	12.8	11.0	22.9	23.8	6.2	3.1	3.0	9.2	3.5	13.7	14.6
30	13.4	11.2	23.6	24.6	6.9	3.3	3.2	9.3	3.9	14.3	16.0
32	14.1	11.5	24.3	25.5	7.7	3.6	3.5	9.4	4.3	14.9	17.5
34	14.8	11.7	25.1	26.5	8.6	3.9	3.8	9.4	4.8	15.6	19.1
36	15.6	12.0	25.9	27.5	9.5	4.2	4.1	9.5	5.3	16.4	20.9
38	16.4	12.3	26.8	28.7	10.5	4.5	4.4	9.6	5.8	17.3	22.7
40	17.4	12.6	27.9	30.0	11.7	4.8	4.7	9.7	6.5	18.2	24.6
42	18.5	12.9	29.0	31.5	12.9	5.2	5.0	9.8	7.2	19.3	26.7
44	19.8	13.3	30.3	33.1	14.4	5.5	5.4	9.8	8.0	20.5	29.0
46	21.3	13.7	31.8	35.0	16.1	5.9	5.7	9.9	8.9	21.9	31.4
48	23.0	14.1	33.5	37.1	18.0	6.3	6.1	10.0	10.0	23.5	34.1
50	25.1	14.6	35.5	39.6	20.2	6.7	6.5	10.1	11.2	25.3	37.1
52	27.6	15.0	37.8	42.6	22.9	7.2	6.9	10.2	12.7	27.6	40.3
54	30.7	15.6	40.7	46.3	26.3	7.6	7.4	10.4	14.6	30.4	44.0
56	34.6	16.2	44.4	50.9	30.5	8.2	7.9	10.5	16.9	33.9	48.2
58	40.0	16.9	49.2	56.9	36.2	8.7	8.5	10.6	20.1	38.6	53.0
60	47.6	17.7	56.0	65.4	44.2	9.4	9.1	10.8	24.5	45.3	58.9
62	59.9	18.7	66.8	78.6	56.9	10.2	9.9	11.0	31.6	55.9	66.2
64	84.5	20.0	88.0	104.5	82.1	11.1	10.8	11.2	45.6	76.8	76.3
66	186.7	22.2	174.3	208.8	185.4	12.6	12.2	11.6	102.8	162.7	94.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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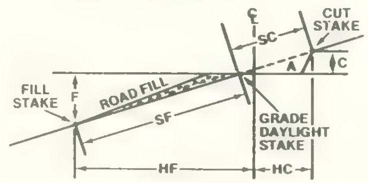
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

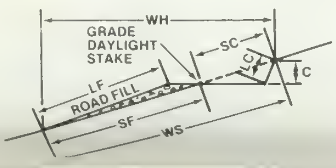
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 17 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.4	9.6	18.9	19.0	1.7	1.1	1.0	9.0	.9	9.9	4.3
12	9.7	9.8	19.3	19.4	2.1	1.3	1.2	9.1	1.2	10.2	5.3
14	10.0	10.0	19.8	20.0	2.5	1.5	1.4	9.2	1.4	10.6	6.4
16	10.3	10.2	20.3	20.5	2.9	1.8	1.6	9.3	1.6	10.9	7.4
18	10.7	10.4	20.8	21.1	3.4	2.1	1.8	9.4	1.9	11.3	8.6
20	11.1	10.6	21.3	21.7	3.9	2.3	2.1	9.5	2.2	11.8	9.8
22	11.5	10.9	21.9	22.4	4.5	2.6	2.3	9.7	2.5	12.2	11.0
24	12.0	11.1	22.5	23.1	5.1	2.9	2.6	9.8	2.8	12.7	12.4
26	12.5	11.4	23.2	23.9	5.7	3.2	2.9	9.9	3.2	13.2	13.8
28	13.1	11.7	23.9	24.8	6.4	3.5	3.1	10.1	3.5	13.8	15.2
30	13.7	12.0	24.6	25.7	7.1	3.9	3.4	10.2	3.9	14.4	16.8
32	14.4	12.3	25.5	26.7	7.9	4.2	3.8	10.4	4.4	15.1	18.5
34	15.2	12.7	26.4	27.9	8.8	4.6	4.1	10.5	4.9	15.8	20.3
36	16.0	13.0	27.4	29.1	9.8	4.9	4.4	10.7	5.4	16.7	22.2
38	17.0	13.4	28.4	30.4	10.9	5.3	4.8	10.9	6.0	17.6	24.3
40	18.1	13.9	29.6	31.9	12.1	5.8	5.1	11.1	6.7	18.6	26.5
42	19.3	14.3	31.0	33.6	13.5	6.2	5.5	11.3	7.5	19.7	28.9
44	20.7	14.8	32.5	35.5	15.0	6.7	6.0	11.5	8.3	21.0	31.5
46	22.3	15.3	34.2	37.6	16.8	7.2	6.4	11.7	9.3	22.5	34.4
48	24.2	15.9	36.1	40.1	18.9	7.7	6.9	11.9	10.5	24.2	37.5
50	26.4	16.5	38.4	42.9	21.3	8.3	7.4	12.2	11.8	26.2	41.0
52	29.1	17.2	41.1	46.4	24.2	8.9	7.9	12.5	13.4	28.7	45.0
54	32.5	18.0	44.5	50.5	27.9	9.6	8.6	12.8	15.5	31.7	49.4
56	36.9	18.9	48.6	55.8	32.5	10.3	9.2	13.1	18.0	35.5	54.6
58	42.8	19.8	54.2	62.6	39.7	11.1	10.0	13.5	21.5	40.7	60.7
60	51.2	21.0	61.9	72.2	47.5	12.1	10.8	13.9	26.4	48.0	68.1
62	64.9	22.4	74.2	87.3	61.6	13.2	11.8	14.4	34.2	59.8	77.6
64	92.2	24.3	98.1	116.5	89.6	14.6	13.1	15.0	49.7	83.1	90.8
66	206.2	27.3	194.9	233.5	204.8	16.8	15.1	16.0	113.6	178.9	115.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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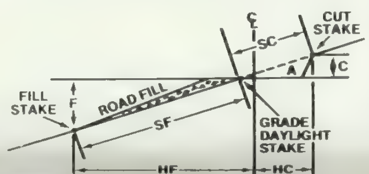
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



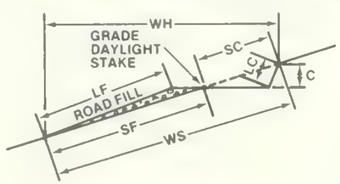
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 17 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.4	9.8	19.1	19.2	1.7	1.2	1.0	9.2	.9	9.9	4.4
12	9.7	10.0	19.6	19.8	2.1	1.5	1.2	9.4	1.2	10.2	5.4
14	10.1	10.3	20.2	20.4	2.5	1.8	1.4	9.6	1.4	10.6	6.5
16	10.5	10.5	20.7	21.0	3.0	2.1	1.7	9.7	1.7	11.0	7.6
18	10.9	10.8	21.3	21.7	3.5	2.4	1.9	9.9	1.9	11.4	8.8
20	11.3	11.1	22.0	22.4	4.0	2.7	2.2	10.1	2.2	11.8	10.1
22	11.8	11.4	22.6	23.2	4.6	3.1	2.5	10.3	2.5	12.3	11.4
24	12.3	11.8	23.3	24.0	5.2	3.4	2.7	10.6	2.9	12.8	12.8
26	12.8	12.1	24.1	24.9	5.8	3.8	3.0	10.8	3.2	13.3	14.4
28	13.4	12.5	25.0	25.9	6.5	4.2	3.4	11.0	3.6	13.9	16.0
30	14.1	12.9	25.9	27.0	7.3	4.6	3.7	11.3	4.1	14.6	17.7
32	14.9	13.3	26.8	28.2	8.2	5.1	4.1	11.5	4.5	15.3	19.6
34	15.7	13.8	27.9	29.5	9.1	5.5	4.4	11.8	5.0	16.1	21.6
36	16.6	14.3	29.1	30.9	10.1	6.1	4.8	12.1	5.6	16.9	23.8
38	17.6	14.8	30.3	32.5	11.3	6.6	5.3	12.5	6.3	17.9	26.1
40	18.8	15.4	31.8	34.2	12.6	7.2	5.7	12.8	7.0	19.0	28.7
42	20.1	16.0	33.4	36.2	14.1	7.8	6.2	13.2	7.8	20.2	31.5
44	21.7	16.7	35.1	38.4	15.7	8.4	6.7	13.6	8.7	21.6	34.6
46	23.4	17.5	37.2	40.9	17.6	9.1	7.3	14.0	9.8	23.2	38.0
48	25.5	18.3	39.5	43.8	19.9	9.9	7.9	14.4	11.0	25.1	41.8
50	28.0	19.2	42.2	47.2	22.6	10.7	8.6	14.9	12.5	27.3	46.1
52	31.0	20.2	45.5	51.3	25.8	11.7	9.3	15.5	14.3	30.0	51.0
54	34.8	21.3	49.4	56.2	29.8	12.7	10.1	16.1	16.5	33.3	56.7
56	39.7	22.6	54.4	62.4	35.0	13.8	11.1	16.8	19.4	37.6	63.3
58	46.4	24.1	61.0	70.5	41.9	15.1	12.1	17.6	23.3	43.4	71.3
60	55.9	25.9	70.2	81.8	51.9	16.6	13.3	18.5	28.8	51.7	81.2
62	71.5	28.0	84.6	99.5	67.9	18.5	14.8	19.6	37.7	65.0	94.2
64	102.8	30.9	112.6	133.7	99.9	20.8	16.7	21.0	55.4	91.6	112.8
66	233.9	35.7	225.0	269.6	232.3	24.6	19.7	23.2	128.8	201.8	148.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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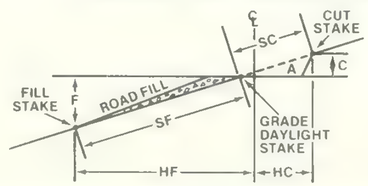
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

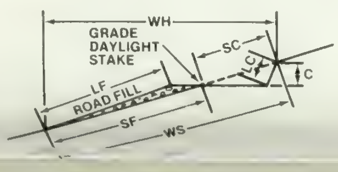
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 17 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.5	10.0	19.4	19.5	1.7	1.4	1.0	9.5	.9	9.9	4.5
12	9.8	10.3	20.0	20.1	2.1	1.7	1.2	9.7	1.2	10.3	5.5
14	10.2	10.6	20.6	20.8	2.5	2.1	1.5	10.0	1.4	10.6	6.6
16	10.6	10.9	21.2	21.5	3.0	2.4	1.7	10.2	1.7	11.0	7.8
18	11.0	11.3	21.9	22.3	3.5	2.8	2.0	10.5	2.0	11.4	9.1
20	11.5	11.6	22.7	23.1	4.1	3.2	2.3	10.8	2.2	11.9	10.4
22	12.0	12.0	23.4	24.0	4.6	3.7	2.6	11.1	2.6	12.4	11.9
24	12.5	12.5	24.3	25.0	5.3	4.1	2.9	11.4	2.9	12.9	13.4
26	13.1	12.9	25.2	26.0	6.0	4.6	3.3	11.8	3.3	13.5	15.0
28	13.8	13.4	26.2	27.2	6.7	5.1	3.6	12.1	3.7	14.1	16.8
30	14.5	14.0	27.3	28.5	7.5	5.7	4.0	12.5	4.2	14.8	18.8
32	15.3	14.5	28.4	29.9	8.4	6.3	4.4	12.9	4.7	15.5	20.8
34	16.2	15.2	29.7	31.4	9.4	6.9	4.9	13.4	5.2	16.3	23.1
36	17.2	15.8	31.1	33.1	10.5	7.6	5.4	13.9	5.8	17.3	25.6
38	18.4	16.6	32.7	35.0	11.8	8.3	5.9	14.4	6.5	18.3	28.3
40	19.7	17.4	34.4	37.1	13.2	9.1	6.5	15.0	7.3	19.5	31.4
42	21.1	18.3	36.4	39.4	14.8	10.0	7.1	15.6	8.2	20.8	34.7
44	22.8	19.3	38.6	42.1	16.6	11.0	7.8	16.3	9.2	22.3	38.4
46	24.8	20.4	41.1	45.2	18.7	12.1	8.5	17.0	10.4	24.1	42.7
48	27.2	21.6	44.0	48.8	21.2	13.2	9.4	17.9	11.8	26.1	47.5
50	30.0	23.0	47.4	53.0	24.2	14.6	10.3	18.8	13.4	28.6	53.0
52	33.5	24.6	51.5	58.0	27.8	16.0	11.3	19.8	15.4	31.7	59.3
54	37.8	26.4	56.5	64.2	32.4	17.7	12.5	21.0	18.0	35.5	66.9
56	43.5	28.5	62.8	72.0	38.3	19.7	13.9	22.4	21.3	40.4	76.0
58	51.3	30.9	71.1	82.2	46.4	21.9	15.5	24.0	25.7	47.1	87.2
60	62.6	33.9	82.7	96.5	58.0	24.7	17.5	26.0	32.2	56.8	101.5
62	81.0	37.7	100.9	118.7	77.0	28.1	19.9	28.4	42.7	72.5	121.0
64	118.6	42.9	136.0	161.5	115.3	32.7	23.1	31.6	63.9	104.4	150.3
66	278.1	51.7	275.3	329.8	276.2	40.3	28.5	37.0	153.2	238.3	209.1

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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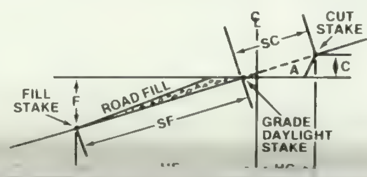
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

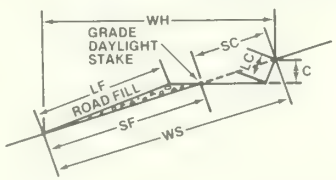
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 17 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.6	10.5	20.0	20.1	1.7	1.9	1.0	10.1	1.0	9.9	4.6
12	10.0	10.9	20.7	20.9	2.2	2.3	1.3	10.4	1.2	10.3	5.7
14	10.4	11.3	21.5	21.7	2.6	2.8	1.6	10.9	1.4	10.7	6.9
16	10.9	11.8	22.4	22.7	3.1	3.4	1.9	11.3	1.7	11.1	8.2
18	11.4	12.3	23.3	23.7	3.6	3.9	2.2	11.8	2.0	11.5	9.6
20	11.9	12.9	24.3	24.8	4.2	4.6	2.5	12.3	2.3	12.0	11.2
22	12.5	13.5	25.4	26.0	4.8	5.2	2.9	12.9	2.7	12.5	12.8
24	13.1	14.2	26.6	27.3	5.5	6.0	3.3	13.5	3.1	13.1	14.7
26	13.8	15.0	27.9	28.8	6.3	6.8	3.8	14.2	3.5	13.7	16.7
28	14.6	15.8	29.3	30.4	7.1	7.7	4.3	14.9	3.9	14.4	18.9
30	15.5	16.8	30.9	32.3	8.0	8.7	4.8	15.7	4.4	15.2	21.3
32	16.5	17.9	32.7	34.3	9.0	9.8	5.4	16.7	5.0	16.0	24.1
34	17.6	19.1	34.7	36.6	10.2	11.1	6.1	17.7	5.7	17.0	27.1
36	18.8	20.4	37.0	39.3	11.5	12.5	6.9	18.9	6.4	18.1	30.6
38	20.3	22.0	39.5	42.3	13.0	14.1	7.8	20.2	7.2	19.3	34.6
40	22.0	23.8	42.5	45.8	14.7	15.9	8.8	21.8	8.2	20.7	39.1
42	23.9	25.9	45.9	49.8	16.7	18.1	10.0	23.6	9.3	22.4	44.4
44	26.2	28.4	50.0	54.6	19.0	20.6	11.4	25.7	10.6	24.3	50.6
46	29.0	31.4	54.8	60.4	21.8	23.7	13.1	28.2	12.1	26.7	58.0
48	32.3	35.0	60.7	67.3	25.2	27.3	15.2	31.2	14.0	29.5	67.1
50	36.5	39.6	68.0	76.0	29.4	31.9	17.7	35.0	16.3	33.0	78.2
52	41.8	45.3	77.3	87.1	34.7	37.7	20.9	39.9	19.3	37.4	92.5
54	48.8	52.9	89.5	101.7	41.8	45.3	25.1	46.2	23.2	43.3	111.2
56	58.4	63.4	106.2	121.8	51.5	55.8	31.0	54.9	28.5	51.3	136.9
58	72.5	78.7	130.8	151.2	65.6	71.1	39.5	67.7	36.4	63.1	174.5
60	95.1	103.2	170.0	198.3	88.2	95.7	53.1	88.1	48.9	81.9	234.7
62	137.1	148.7	242.9	285.7	130.2	141.2	78.3	126.0	72.2	116.8	346.5
64	242.0	262.5	425.0	504.6	235.2	255.1	141.5	220.8	130.5	204.2	625.9
66	977.1	1059.8	1700.0	2036.9	970.3	1052.4	583.8	884.2	538.2	815.8	2581.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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LF = LENGTH OF FILL SLOPE
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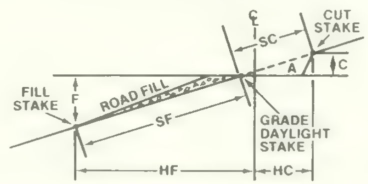
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

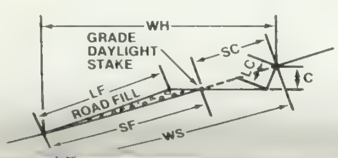
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 18 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.8	9.8	19.5	19.6	1.8	1.0	1.0	9.0	1.0	10.5	4.7
12	10.1	9.9	19.8	19.9	2.2	1.2	1.2	9.0	1.2	10.8	5.8
14	10.4	10.0	20.2	20.4	2.6	1.4	1.4	9.0	1.4	11.2	6.9
16	10.7	10.1	20.5	20.8	3.0	1.6	1.6	9.0	1.7	11.5	8.0
18	11.0	10.2	20.9	21.3	3.5	1.8	1.8	9.0	2.0	11.9	9.1
20	11.4	10.4	21.4	21.8	4.0	2.0	2.0	9.0	2.2	12.4	10.3
22	11.8	10.5	21.8	22.3	4.6	2.3	2.3	9.0	2.5	12.8	11.6
24	12.3	10.7	22.3	22.9	5.2	2.5	2.5	9.0	2.9	13.3	12.9
26	12.8	10.8	22.8	23.6	5.8	2.7	2.7	9.0	3.2	13.8	14.2
28	13.3	11.0	23.4	24.3	6.5	3.0	3.0	9.0	3.6	14.4	15.7
30	13.9	11.2	24.0	25.0	7.2	3.2	3.2	9.0	4.0	15.0	17.1
32	14.5	11.4	24.6	25.9	8.0	3.5	3.5	9.0	4.4	15.6	18.7
34	15.2	11.6	25.3	26.8	8.8	3.7	3.7	9.0	4.9	16.3	20.3
36	16.0	11.8	26.1	27.8	9.8	4.0	4.0	9.0	5.4	17.1	22.1
38	16.9	12.0	27.0	28.9	10.8	4.3	4.3	9.0	6.0	18.0	23.9
40	17.9	12.2	27.9	30.1	12.0	4.5	4.5	9.0	6.6	18.9	25.9
42	19.0	12.5	29.0	31.5	13.2	4.8	4.8	9.0	7.3	20.0	27.9
44	20.2	12.8	30.2	33.0	14.7	5.2	5.2	9.0	8.1	21.2	30.2
46	21.7	13.1	31.6	34.8	16.3	5.5	5.5	9.0	9.1	22.6	32.5
48	23.4	13.4	33.2	36.8	18.2	5.8	5.8	9.0	10.1	24.2	35.1
50	25.4	13.8	35.0	39.2	20.5	6.2	6.2	9.0	11.4	26.0	37.9
52	27.8	14.2	37.3	42.0	23.2	6.5	6.5	9.0	12.8	28.3	41.1
54	30.9	14.6	40.0	45.5	26.4	6.9	6.9	9.0	14.7	31.0	44.5
56	34.7	15.1	43.5	49.8	30.6	7.4	7.4	9.0	17.0	34.5	48.4
58	39.9	15.6	48.1	55.6	36.1	7.8	7.8	9.0	20.0	39.1	52.9
60	47.4	16.3	54.6	63.6	44.0	8.4	8.4	9.0	24.4	45.6	58.3
62	59.3	17.0	64.9	76.4	56.4	9.0	9.0	9.0	31.3	55.9	64.9
64	83.2	18.0	85.3	101.2	80.8	9.7	9.7	9.0	44.8	76.3	73.9
66	182.1	19.7	168.4	201.8	180.8	10.9	10.9	9.0	100.3	159.4	89.6

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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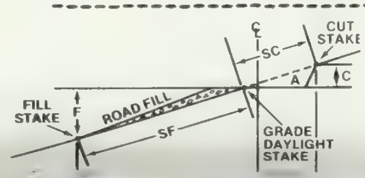
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

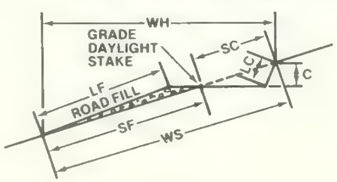
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 18 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.8	9.9	19.6	19.7	1.8	1.0	1.0	9.1	1.0	10.5	4.8
12	10.1	10.0	19.9	20.1	2.2	1.2	1.2	9.1	1.2	10.8	5.8
14	10.4	10.1	20.3	20.5	2.6	1.4	1.4	9.1	1.4	11.2	6.9
16	10.7	10.2	20.7	21.0	3.1	1.6	1.6	9.2	1.7	11.5	8.0
18	11.1	10.4	21.1	21.5	3.5	1.8	1.8	9.2	2.0	11.9	9.2
20	11.5	10.5	21.6	22.0	4.1	2.1	2.1	9.2	2.3	12.4	10.4
22	11.9	10.7	22.1	22.6	4.6	2.3	2.3	9.2	2.6	12.8	11.7
24	12.4	10.9	22.6	23.2	5.2	2.5	2.5	9.3	2.9	13.3	13.1
26	12.9	11.0	23.1	23.9	5.8	2.8	2.8	9.3	3.2	13.9	14.5
28	13.4	11.2	23.7	24.6	6.5	3.0	3.0	9.3	3.6	14.4	15.9
30	14.0	11.4	24.4	25.4	7.3	3.3	3.3	9.3	4.0	15.0	17.5
32	14.7	11.7	25.1	26.3	8.1	3.6	3.6	9.4	4.5	15.7	19.1
34	15.4	11.9	25.8	27.3	8.9	3.8	3.8	9.4	5.0	16.4	20.8
36	16.2	12.1	26.6	28.3	9.9	4.1	4.1	9.4	5.5	17.2	22.6
38	17.1	12.4	27.5	29.5	10.9	4.4	4.4	9.4	6.1	18.1	24.5
40	18.1	12.7	28.5	30.7	12.1	4.7	4.7	9.5	6.7	19.1	26.5
42	19.2	13.0	29.7	32.2	13.4	5.0	5.0	9.5	7.4	20.2	28.7
44	20.5	13.3	30.9	33.8	14.9	5.4	5.3	9.5	8.3	21.4	31.0
46	22.0	13.6	32.4	35.6	16.6	5.7	5.7	9.6	9.2	22.8	33.6
48	23.8	14.0	34.0	37.8	18.5	6.1	6.1	9.6	10.3	24.4	36.3
50	25.8	14.4	36.0	40.2	20.8	6.5	6.4	9.6	11.6	26.3	39.3
52	28.4	14.8	38.3	43.2	23.6	6.9	6.8	9.7	13.1	28.6	42.6
54	31.5	15.3	41.2	46.8	27.0	7.3	7.3	9.7	15.0	31.4	46.3
56	35.5	15.8	44.8	51.3	31.2	7.8	7.7	9.8	17.3	35.0	50.5
58	40.8	16.5	49.6	57.3	36.9	8.3	8.3	9.8	20.5	39.7	55.3
60	48.5	17.2	56.3	65.7	45.0	8.9	8.8	9.9	25.0	46.5	61.1
62	60.9	18.0	67.1	78.9	57.8	9.6	9.5	10.0	32.1	57.1	68.3
64	85.5	19.2	88.2	104.7	83.1	10.4	10.3	10.0	46.1	78.2	78.1
66	187.8	21.1	174.4	208.9	186.5	11.7	11.6	10.2	103.5	164.2	95.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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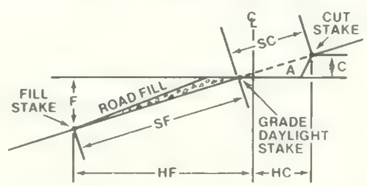
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

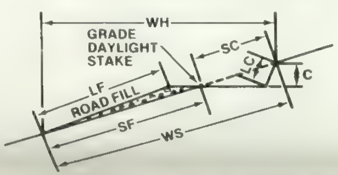
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 18 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.8	10.0	19.7	19.8	1.8	1.0	1.0	9.2	1.0	10.5	4.8
12	10.1	10.1	20.1	20.3	2.2	1.2	1.2	9.3	1.2	10.8	5.9
14	10.5	10.3	20.5	20.7	2.6	1.5	1.4	9.4	1.5	11.2	7.0
16	10.8	10.4	21.0	21.2	3.1	1.7	1.6	9.4	1.7	11.6	8.1
18	11.2	10.6	21.4	21.8	3.6	1.9	1.9	9.5	2.0	12.0	9.4
20	11.6	10.8	21.9	22.4	4.1	2.2	2.1	9.5	2.3	12.4	10.6
22	12.0	11.0	22.5	23.0	4.7	2.4	2.4	9.6	2.6	12.9	12.0
24	12.5	11.2	23.0	23.7	5.3	2.7	2.6	9.7	2.9	13.4	13.3
26	13.0	11.4	23.6	24.4	5.9	3.0	2.9	9.7	3.3	13.9	14.8
28	13.6	11.6	24.3	25.2	6.6	3.2	3.1	9.8	3.7	14.5	16.3
30	14.2	11.9	25.0	26.1	7.4	3.5	3.4	9.9	4.1	15.1	17.9
32	14.9	12.1	25.7	27.0	8.2	3.8	3.7	9.9	4.5	15.8	19.7
34	15.6	12.4	26.5	28.0	9.1	4.1	4.0	10.0	5.0	16.5	21.5
36	16.5	12.7	27.4	29.2	10.1	4.4	4.3	10.1	5.6	17.4	23.4
38	17.4	13.0	28.4	30.4	11.1	4.8	4.6	10.2	6.2	18.3	25.4
40	18.4	13.3	29.5	31.8	12.4	5.1	5.0	10.2	6.9	19.3	27.6
42	19.6	13.7	30.7	33.3	13.7	5.5	5.3	10.3	7.6	20.4	30.0
44	21.0	14.1	32.1	35.1	15.2	5.8	5.7	10.4	8.5	21.7	32.5
46	22.6	14.5	33.7	37.0	17.0	6.2	6.1	10.5	9.4	23.1	35.2
48	24.4	14.9	35.5	39.3	19.0	6.7	6.5	10.6	10.6	24.8	38.2
50	26.6	15.4	37.5	42.0	21.4	7.1	6.9	10.7	11.9	26.8	41.5
52	29.2	15.9	40.1	45.1	24.3	7.6	7.4	10.8	13.5	29.2	45.2
54	32.5	16.5	43.1	49.0	27.8	8.1	7.8	11.0	15.4	32.2	49.3
56	36.7	17.2	47.0	53.8	32.3	8.6	8.4	11.1	17.9	35.9	54.0
58	42.3	17.9	52.1	60.2	38.3	9.3	9.0	11.2	21.2	40.9	59.5
60	50.4	18.8	59.3	69.2	46.8	10.0	9.7	11.4	25.9	47.9	66.0
62	63.4	19.8	70.8	83.3	60.3	10.8	10.4	11.6	33.4	59.2	74.2
64	89.5	21.2	93.2	110.7	87.0	11.8	11.4	11.9	48.2	81.4	85.5
66	197.7	23.5	184.5	221.1	196.3	13.3	12.9	12.2	108.9	172.3	105.7

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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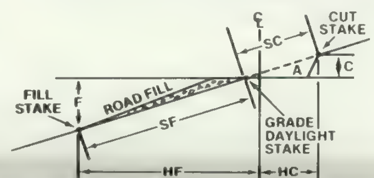
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

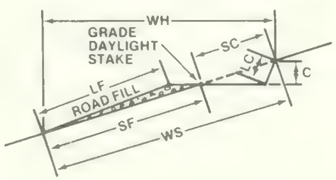
ROAD GEOMETRY DATA USING

ROAD WIDTH = 18 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	9.9	10.2	20.0	20.1	1.8	1.1	1.0	9.5	1.0	10.5	4.9
12	10.2	10.4	20.4	20.6	2.2	1.4	1.2	9.6	1.2	10.8	6.0
14	10.6	10.6	20.9	21.1	2.6	1.6	1.5	9.7	1.5	11.2	7.1
16	10.9	10.8	21.4	21.7	3.1	1.9	1.7	9.9	1.7	11.6	8.3
18	11.3	11.0	22.0	22.3	3.6	2.2	2.0	10.0	2.0	12.0	9.6
20	11.8	11.2	22.6	23.0	4.2	2.5	2.2	10.1	2.3	12.5	11.0
22	12.2	11.5	23.2	23.7	4.7	2.8	2.5	10.2	2.6	12.9	12.4
24	12.7	11.8	23.8	24.5	5.4	3.1	2.7	10.4	3.0	13.5	13.8
26	13.3	12.1	24.5	25.3	6.0	3.4	3.0	10.5	3.3	14.0	15.4
28	13.9	12.4	25.3	26.3	6.8	3.7	3.3	10.7	3.7	14.6	17.1
30	14.5	12.7	26.1	27.2	7.5	4.1	3.6	10.8	4.2	15.3	18.8
32	15.3	13.0	27.0	28.3	8.4	4.4	4.0	11.0	4.7	16.0	20.7
34	16.1	13.4	27.9	29.5	9.3	4.8	4.3	11.2	5.2	16.8	22.7
36	17.0	13.8	29.0	30.8	10.4	5.2	4.7	11.3	5.8	17.6	24.9
38	18.0	14.2	30.1	32.2	11.5	5.6	5.1	11.5	6.4	18.6	27.2
40	19.1	14.7	31.4	33.8	12.8	6.1	5.4	11.7	7.1	19.7	29.7
42	20.4	15.2	32.8	35.6	14.3	6.6	5.9	11.9	7.9	20.9	32.4
44	21.9	15.7	34.4	37.6	15.9	7.1	6.3	12.2	8.8	22.2	35.3
46	23.6	16.2	36.2	39.8	17.8	7.6	6.8	12.4	9.9	23.8	38.5
48	25.6	16.8	38.3	42.4	20.0	8.1	7.3	12.6	11.1	25.6	42.1
50	28.0	17.5	40.7	45.5	22.5	8.8	7.8	12.9	12.5	27.8	46.0
52	30.8	18.2	43.6	49.1	25.7	9.4	8.4	13.2	14.2	30.3	50.4
54	34.4	19.1	47.1	53.5	29.5	10.1	9.1	13.5	16.4	33.5	55.4
56	39.1	20.0	51.5	59.0	34.4	10.9	9.8	13.9	19.1	37.6	61.2
58	45.3	21.0	57.4	66.3	41.0	11.8	10.5	14.3	22.7	43.1	68.1
60	54.2	22.2	65.6	76.5	50.3	12.8	11.4	14.7	27.9	50.9	76.4
62	68.7	23.7	78.5	92.4	65.2	14.0	12.5	15.3	36.2	63.3	87.0
64	97.6	25.7	103.9	123.3	94.9	15.5	13.8	15.9	52.6	87.9	101.8
66	218.3	28.9	206.4	247.3	216.8	17.8	15.9	17.0	120.3	189.4	128.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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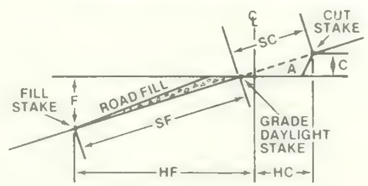
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

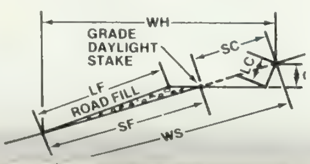
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 18 FEET

CUT SLOPE = .75 TO 1

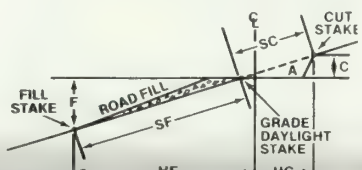
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.0	10.4	20.3	20.4	1.8	1.3	1.0	9.8	1.0	10.5	4.9
12	10.3	10.6	20.8	20.9	2.2	1.6	1.3	9.9	1.2	10.8	6.1
14	10.7	10.9	21.4	21.6	2.7	1.9	1.5	10.1	1.5	11.2	7.3
16	11.1	11.2	21.9	22.2	3.2	2.2	1.8	10.3	1.7	11.6	8.5
18	11.5	11.4	22.6	22.9	3.7	2.5	2.0	10.5	2.0	12.1	9.9
20	11.9	11.8	23.2	23.7	4.2	2.9	2.3	10.7	2.3	12.5	11.3
22	12.4	12.1	24.0	24.5	4.8	3.2	2.6	10.9	2.7	13.0	12.8
24	13.0	12.4	24.7	25.4	5.5	3.6	2.9	11.2	3.0	13.5	14.4
26	13.6	12.8	25.5	26.4	6.2	4.0	3.2	11.4	3.4	14.1	16.1
28	14.2	13.2	26.4	27.4	6.9	4.5	3.6	11.7	3.8	14.8	17.9
30	14.9	13.6	27.4	28.6	7.7	4.9	3.9	11.9	4.3	15.4	19.9
32	15.7	14.1	28.4	29.8	8.6	5.4	4.3	12.2	4.8	16.2	22.0
34	16.6	14.6	29.5	31.2	9.6	5.9	4.7	12.5	5.3	17.0	24.2
36	17.6	15.1	30.8	32.7	10.7	6.4	5.1	12.8	6.0	17.9	26.6
38	18.7	15.7	32.1	34.4	12.0	7.0	5.6	13.2	6.6	18.9	29.3
40	19.9	16.3	33.6	36.2	13.3	7.6	6.1	13.5	7.4	20.1	32.1
42	21.3	17.0	35.3	38.3	14.9	8.2	6.6	13.9	8.3	21.4	35.3
44	22.9	17.7	37.2	40.6	16.6	8.9	7.1	14.4	9.2	22.9	38.8
46	24.8	18.5	39.4	43.3	18.7	9.7	7.7	14.8	10.4	24.5	42.6
48	27.0	19.4	41.8	46.4	21.1	10.5	8.4	15.3	11.7	26.5	46.9
50	29.6	20.3	44.7	50.0	23.9	11.4	9.1	15.8	13.3	28.9	51.7
52	32.9	21.4	48.1	54.3	27.3	12.3	9.9	16.4	15.2	31.7	57.2
54	36.9	22.6	52.3	59.5	31.6	13.4	10.7	17.1	17.5	35.3	63.6
56	42.1	24.0	57.6	66.0	37.1	14.6	11.7	17.8	20.6	39.8	71.0
58	49.1	25.5	64.5	74.6	44.4	16.0	12.8	18.6	24.6	45.9	80.0
60	59.2	27.4	74.3	86.6	54.9	17.6	14.1	19.6	30.5	54.7	91.1
62	75.7	29.7	89.5	105.4	71.9	19.6	15.6	20.7	39.9	68.8	105.6
64	108.8	32.7	119.2	141.5	105.7	22.1	17.6	22.2	58.6	97.0	126.4
66	247.7	37.8	238.3	285.5	245.9	26.0	20.8	24.6	136.4	213.6	165.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

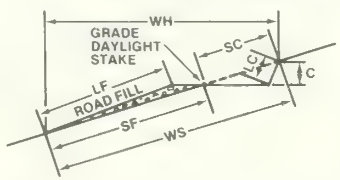
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 18 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.1	10.6	20.6	20.7	1.8	1.5	1.1	10.1	1.0	10.5	5.0
12	10.4	10.9	21.2	21.3	2.2	1.8	1.3	10.3	1.2	10.9	6.2
14	10.8	11.2	21.8	22.0	2.7	2.2	1.6	10.6	1.5	11.2	7.4
16	11.2	11.6	22.5	22.8	3.2	2.6	1.8	10.8	1.8	11.7	8.8
18	11.7	11.9	23.2	23.6	3.7	3.0	2.1	11.1	2.1	12.1	10.2
20	12.1	12.3	24.0	24.5	4.3	3.4	2.4	11.4	2.4	12.6	11.7
22	12.7	12.7	24.8	25.4	4.9	3.9	2.7	11.7	2.7	13.1	13.3
24	13.3	13.2	25.7	26.4	5.6	4.4	3.1	12.1	3.1	13.6	15.0
26	13.9	13.7	26.7	27.6	6.3	4.9	3.4	12.4	3.5	14.2	16.9
28	14.6	14.2	27.7	28.8	7.1	5.4	3.8	12.8	3.9	14.9	18.9
30	15.4	14.8	28.9	30.1	8.0	6.0	4.2	13.2	4.4	15.6	21.0
32	16.2	15.4	30.1	31.6	8.9	6.6	4.7	13.7	4.9	16.4	23.4
34	17.2	16.1	31.5	33.2	10.0	7.3	5.2	14.2	5.5	17.3	25.9
36	18.2	16.8	33.0	35.0	11.1	8.0	5.7	14.7	6.2	18.3	28.7
38	19.4	17.6	34.6	37.0	12.5	8.8	6.2	15.2	6.9	19.4	31.8
40	20.8	18.4	36.4	39.2	13.9	9.7	6.8	15.8	7.7	20.6	35.2
42	22.4	19.4	38.5	41.8	15.6	10.6	7.5	16.5	8.7	22.0	38.9
44	24.2	20.4	40.8	44.6	17.6	11.6	8.2	17.2	9.7	23.6	43.1
46	26.3	21.6	43.5	47.9	19.8	12.8	9.0	18.0	11.0	25.5	47.8
48	28.8	22.9	46.6	51.7	22.4	14.0	9.9	18.9	12.5	27.7	53.2
50	31.8	24.4	50.2	56.1	25.6	15.4	10.9	19.9	14.2	30.3	59.4
52	35.4	26.0	54.5	61.5	29.5	17.0	12.0	21.0	16.4	33.5	66.5
54	40.1	27.9	59.8	68.0	34.3	18.8	13.3	22.3	19.0	37.6	75.0
56	46.1	30.1	66.5	76.2	40.6	20.8	14.7	23.7	22.5	42.8	85.2
58	54.3	32.7	75.3	87.0	49.1	23.2	16.4	25.4	27.2	49.8	97.7
60	66.2	35.9	87.6	102.2	61.4	26.1	18.5	27.5	34.1	60.1	113.8
62	85.8	39.9	106.8	125.7	81.5	29.8	21.0	30.0	45.2	76.8	135.7
64	125.6	45.4	144.0	171.0	122.1	34.6	24.5	33.5	67.7	110.6	168.5
66	294.4	54.8	291.5	349.2	292.4	42.7	30.2	39.2	162.2	252.3	234.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
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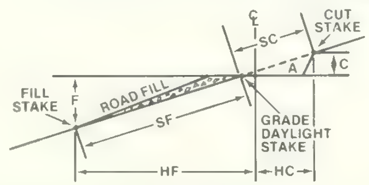
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

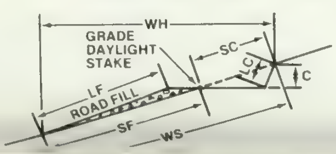
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 18 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.2	11.1	21.2	21.3	1.8	2.0	1.1	10.7	1.0	10.5	5.2
12	10.6	11.5	22.0	22.1	2.3	2.5	1.4	11.1	1.3	10.9	6.4
14	11.0	12.0	22.8	23.0	2.8	3.0	1.7	11.5	1.5	11.3	7.8
16	11.5	12.5	23.7	24.0	3.3	3.6	2.0	12.0	1.8	11.7	9.2
18	12.0	13.0	24.7	25.1	3.8	4.2	2.3	12.5	2.1	12.2	10.8
20	12.6	13.6	25.7	26.2	4.4	4.8	2.7	13.0	2.5	12.7	12.5
22	13.2	14.3	26.9	27.5	5.1	5.5	3.1	13.6	2.8	13.3	14.4
24	13.9	15.0	28.1	28.9	5.8	6.3	3.5	14.3	3.2	13.9	16.4
26	14.6	15.9	29.5	30.5	6.6	7.2	4.0	15.0	3.7	14.5	18.7
28	15.5	16.8	31.0	32.2	7.5	8.2	4.5	15.8	4.2	15.3	21.2
30	16.4	17.8	32.7	34.2	8.5	9.2	5.1	16.7	4.7	16.1	23.9
32	17.4	18.9	34.6	36.3	9.6	10.4	5.8	17.6	5.3	17.0	27.0
34	18.6	20.2	36.7	38.8	10.8	11.7	6.5	18.7	6.0	18.0	30.4
36	20.0	21.6	39.1	41.6	12.2	13.2	7.3	20.0	6.8	19.1	34.3
38	21.5	23.3	41.9	44.8	13.8	14.9	8.3	21.4	7.6	20.4	38.8
40	23.2	25.2	45.0	48.5	15.6	16.9	9.4	23.0	8.6	22.0	43.9
42	25.3	27.5	48.6	52.8	17.7	19.2	10.6	24.9	9.8	23.7	49.8
44	27.7	30.1	52.9	57.8	20.1	21.8	12.1	27.2	11.2	25.8	56.8
46	30.7	33.3	58.1	63.9	23.1	25.1	13.9	29.8	12.8	28.2	65.1
48	34.2	37.1	64.3	71.3	26.7	28.9	16.1	33.1	14.8	31.2	75.2
50	38.6	41.9	72.0	80.5	31.1	33.8	18.7	37.1	17.3	34.9	87.7
52	44.2	48.0	81.8	92.2	36.8	39.9	22.1	42.2	20.4	39.6	103.7
54	51.6	56.0	94.7	107.7	44.2	48.0	26.6	48.9	24.5	45.8	124.6
56	61.9	67.1	112.5	128.9	54.5	59.1	32.8	58.2	30.2	54.3	153.5
58	76.8	83.3	138.5	160.1	69.4	75.3	41.8	71.7	38.5	66.8	195.7
60	100.7	109.2	180.0	209.9	93.4	101.3	56.2	93.3	51.8	86.7	263.1
62	145.1	157.4	257.1	302.6	137.9	149.5	83.0	133.4	76.5	123.7	388.4
64	256.3	278.0	450.0	534.3	249.1	270.1	149.8	233.8	138.2	216.2	701.7
66	1034.6	1122.1	1800.0	2156.7	1027.4	1114.3	618.1	936.2	569.9	863.8	2894.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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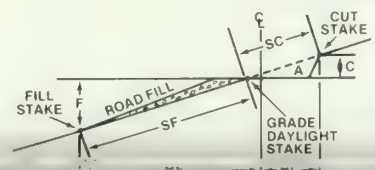
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



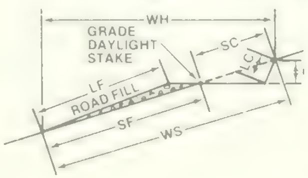
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 19 FEET

CUT SLOPE = VERTICAL

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.3	10.3	20.5	20.6	1.9	1.0	1.0	9.5	1.0	11.0	5.3
12	10.6	10.4	20.9	21.0	2.3	1.2	1.2	9.5	1.3	11.4	6.4
14	10.9	10.5	21.3	21.5	2.7	1.5	1.5	9.5	1.5	11.8	7.6
16	11.3	10.7	21.7	21.9	3.2	1.7	1.7	9.5	1.8	12.2	8.9
18	11.7	10.8	22.1	22.5	3.7	1.9	1.9	9.5	2.1	12.6	10.2
20	12.1	10.9	22.5	23.0	4.3	2.1	2.1	9.5	2.4	13.0	11.5
22	12.5	11.1	23.0	23.6	4.8	2.4	2.4	9.5	2.7	13.5	12.9
24	13.0	11.2	23.5	24.2	5.5	2.6	2.6	9.5	3.0	14.0	14.3
26	13.5	11.4	24.1	24.9	6.1	2.9	2.9	9.5	3.4	14.6	15.9
28	14.0	11.6	24.7	25.6	6.8	3.1	3.1	9.5	3.8	15.2	17.4
30	14.6	11.8	25.3	26.4	7.6	3.4	3.4	9.5	4.2	15.8	19.1
32	15.3	12.0	26.0	27.3	8.4	3.7	3.7	9.5	4.7	16.5	20.8
34	16.1	12.2	26.8	28.3	9.3	3.9	3.9	9.5	5.2	17.3	22.7
36	16.9	12.4	27.6	29.3	10.3	4.2	4.2	9.5	5.7	18.1	24.6
38	17.8	12.7	28.5	30.5	11.4	4.5	4.5	9.5	6.3	19.0	26.6
40	18.8	12.9	29.5	31.8	12.6	4.8	4.8	9.5	7.0	20.0	28.8
42	20.0	13.2	30.6	33.2	14.0	5.1	5.1	9.5	7.7	21.1	31.1
44	21.3	13.5	31.9	34.8	15.5	5.4	5.4	9.5	8.6	22.4	33.6
46	22.9	13.8	33.3	36.7	17.2	5.8	5.8	9.5	9.6	23.8	36.3
48	24.7	14.2	35.0	38.8	19.3	6.1	6.1	9.5	10.7	25.5	39.1
50	26.8	14.5	37.0	41.4	21.6	6.5	6.5	9.5	12.0	27.5	42.3
52	29.4	15.0	39.3	44.3	24.4	6.9	6.9	9.5	13.6	29.8	45.7
54	32.6	15.4	42.2	48.0	27.9	7.3	7.3	9.5	15.5	32.7	49.6
56	36.7	15.9	45.9	52.6	32.3	7.8	7.8	9.5	17.9	36.4	54.0
58	42.2	16.5	50.7	58.6	38.1	8.3	8.3	9.5	21.1	41.2	59.0
60	50.0	17.2	57.6	67.2	46.4	8.8	8.8	9.5	25.7	48.1	64.9
62	62.6	18.0	68.5	80.6	59.5	9.5	9.5	9.5	33.0	59.0	72.3
64	87.8	19.0	90.0	106.8	85.3	10.3	10.3	9.5	47.3	80.5	82.4
66	192.2	20.8	177.8	213.0	190.8	11.5	11.5	9.5	105.9	168.3	99.9

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
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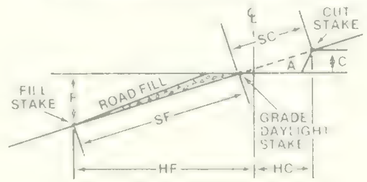
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

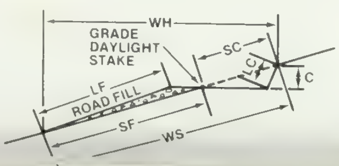
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 19 FEET

CUT SLOPE = .10 TO 1

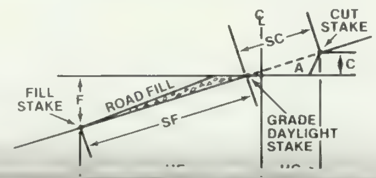
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.3	10.4	20.6	20.8	1.9	1.0	1.0	9.6	1.0	11.0	5.3
12	10.7	10.5	21.0	21.2	2.3	1.3	1.3	9.6	1.3	11.4	6.5
14	11.0	10.7	21.4	21.6	2.7	1.5	1.5	9.6	1.5	11.8	7.7
16	11.3	10.8	21.9	22.1	3.2	1.7	1.7	9.7	1.8	12.2	9.0
18	11.7	11.0	22.3	22.7	3.7	1.9	1.9	9.7	2.1	12.6	10.3
20	12.1	11.1	22.8	23.2	4.3	2.2	2.2	9.7	2.4	13.1	11.6
22	12.6	11.3	23.3	23.8	4.9	2.4	2.4	9.7	2.7	13.6	13.1
24	13.1	11.5	23.8	24.5	5.5	2.7	2.7	9.8	3.0	14.1	14.6
26	13.6	11.7	24.4	25.2	6.2	2.9	2.9	9.8	3.4	14.6	16.1
28	14.1	11.9	25.0	26.0	6.9	3.2	3.2	9.8	3.8	15.2	17.7
30	14.8	12.1	25.7	26.8	7.7	3.5	3.5	9.8	4.2	15.9	19.4
32	15.5	12.3	26.4	27.8	8.5	3.8	3.7	9.9	4.7	16.6	21.2
34	16.2	12.5	27.2	28.8	9.4	4.1	4.0	9.9	5.2	17.3	23.1
36	17.1	12.8	28.1	29.9	10.4	4.4	4.3	9.9	5.8	18.2	25.2
38	18.0	13.1	29.1	31.1	11.5	4.7	4.6	10.0	6.4	19.1	27.3
40	19.1	13.4	30.1	32.5	12.8	5.0	5.0	10.0	7.1	20.1	29.6
42	20.3	13.7	31.3	34.0	14.2	5.3	5.3	10.0	7.9	21.3	32.0
44	21.7	14.0	32.6	35.7	15.7	5.7	5.6	10.1	8.7	22.6	34.6
46	23.2	14.4	34.2	37.6	17.5	6.0	6.0	10.1	9.7	24.1	37.4
48	25.1	14.8	35.9	39.8	19.6	6.4	6.4	10.1	10.9	25.8	40.4
50	27.3	15.2	38.0	42.5	22.0	6.8	6.8	10.2	12.2	27.8	43.8
52	29.9	15.6	40.4	45.6	24.9	7.3	7.2	10.2	13.8	30.2	47.5
54	33.2	16.2	43.4	49.4	28.5	7.7	7.7	10.3	15.8	33.2	51.6
56	37.4	16.7	47.3	54.2	33.0	8.2	8.2	10.3	18.3	36.9	56.3
58	43.1	17.4	52.3	60.5	39.0	8.8	8.7	10.4	21.6	41.9	61.7
60	51.2	18.1	59.5	69.3	47.5	9.4	9.3	10.4	26.4	49.0	68.1
62	64.3	19.0	70.8	83.3	61.0	10.1	10.0	10.5	33.9	60.3	76.1
64	90.3	20.2	93.1	110.5	87.7	11.0	10.9	10.6	48.7	82.5	87.1
66	198.3	22.3	184.0	220.5	196.9	12.3	12.3	10.7	109.2	173.3	106.3

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



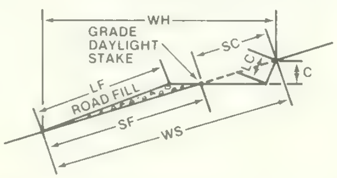
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 19 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.4	10.5	20.8	20.9	1.9	1.1	1.0	9.8	1.0	11.1	5.3
12	10.7	10.7	21.2	21.4	2.3	1.3	1.3	9.8	1.3	11.4	6.5
14	11.0	10.8	21.7	21.9	2.8	1.5	1.5	9.9	1.5	11.8	7.8
16	11.4	11.0	22.1	22.4	3.2	1.8	1.7	9.9	1.8	12.2	9.1
18	11.8	11.2	22.6	23.0	3.8	2.0	2.0	10.0	2.1	12.6	10.4
20	12.2	11.4	23.2	23.6	4.3	2.3	2.2	10.1	2.4	13.1	11.8
22	12.7	11.6	23.7	24.3	4.9	2.6	2.5	10.1	2.7	13.6	13.3
24	13.2	11.8	24.3	25.0	5.5	2.8	2.8	10.2	3.1	14.1	14.9
26	13.7	12.0	24.9	25.8	6.2	3.1	3.0	10.3	3.5	14.7	16.5
28	14.3	12.3	25.6	26.6	7.0	3.4	3.3	10.3	3.9	15.3	18.2
30	15.0	12.5	26.4	27.5	7.8	3.7	3.6	10.4	4.3	16.0	20.0
32	15.7	12.8	27.2	28.5	8.6	4.0	3.9	10.5	4.8	16.7	21.9
34	16.5	13.1	28.0	29.6	9.6	4.3	4.2	10.6	5.3	17.5	23.9
36	17.4	13.4	29.0	30.8	10.6	4.7	4.5	10.6	5.9	18.3	26.1
38	18.4	13.7	30.0	32.1	11.8	5.0	4.9	10.7	6.5	19.3	28.3
40	19.5	14.1	31.2	33.6	13.0	5.4	5.2	10.8	7.2	20.3	30.8
42	20.7	14.5	32.4	35.2	14.5	5.8	5.6	10.9	8.0	21.5	33.4
44	22.2	14.9	33.9	37.0	16.1	6.2	6.0	11.0	8.9	22.9	36.2
46	23.8	15.3	35.5	39.1	17.9	6.6	6.4	11.1	10.0	24.4	39.3
48	25.8	15.8	37.4	41.5	20.1	7.0	6.8	11.2	11.1	26.2	42.6
50	28.1	16.3	39.6	44.3	22.6	7.5	7.3	11.3	12.5	28.3	46.3
52	30.8	16.8	42.3	47.7	25.6	8.0	7.8	11.4	14.2	30.8	50.4
54	34.3	17.4	45.5	51.7	29.4	8.5	8.3	11.6	16.3	33.9	54.9
56	38.7	18.1	49.6	56.8	34.1	9.1	8.9	11.7	18.9	37.9	60.2
58	44.7	18.9	55.0	63.6	40.4	9.8	9.5	11.9	22.4	43.1	66.2
60	53.2	19.8	62.6	73.0	49.4	10.5	10.2	12.0	27.4	50.6	73.5
62	67.0	20.9	74.7	87.9	63.6	11.4	11.0	12.3	35.3	62.4	82.7
64	94.5	22.4	98.4	116.8	91.8	12.4	12.1	12.5	50.9	85.9	95.3
66	208.6	24.8	194.8	233.4	207.2	14.1	13.6	12.9	114.9	181.9	117.7

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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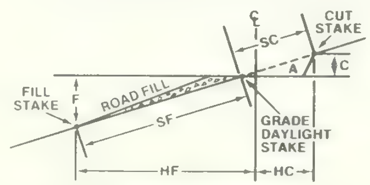
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

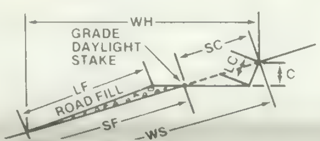
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 19 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.5	10.7	21.1	21.2	1.9	1.2	1.1	10.0	1.0	11.1	5.4
12	10.8	10.9	21.6	21.7	2.3	1.5	1.3	10.2	1.3	11.4	6.7
14	11.2	11.2	22.1	22.3	2.8	1.7	1.5	10.3	1.5	11.8	7.9
16	11.5	11.4	22.6	22.9	3.3	2.0	1.8	10.4	1.8	12.2	9.3
18	12.0	11.6	23.2	23.6	3.8	2.3	2.1	10.5	2.1	12.7	10.7
20	12.4	11.9	23.8	24.3	4.4	2.6	2.3	10.7	2.4	13.2	12.2
22	12.9	12.1	24.5	25.0	5.0	2.9	2.6	10.8	2.8	13.7	13.8
24	13.4	12.4	25.2	25.9	5.7	3.2	2.9	11.0	3.1	14.2	15.4
26	14.0	12.7	25.9	26.8	6.4	3.6	3.2	11.1	3.5	14.8	17.2
28	14.7	13.1	26.7	27.7	7.1	3.9	3.5	11.3	4.0	15.4	19.0
30	15.4	13.4	27.5	28.8	8.0	4.3	3.9	11.4	4.4	16.1	21.0
32	16.1	13.8	28.5	29.9	8.9	4.7	4.2	11.6	4.9	16.9	23.1
34	17.0	14.2	29.5	31.1	9.9	5.1	4.6	11.8	5.5	17.7	25.3
36	17.9	14.6	30.6	32.5	10.9	5.5	4.9	12.0	6.1	18.6	27.7
38	19.0	15.0	31.8	34.0	12.2	6.0	5.3	12.2	6.7	19.6	30.3
40	20.2	15.5	33.1	35.7	13.5	6.4	5.8	12.4	7.5	20.7	33.1
42	21.5	16.0	34.6	37.5	15.0	6.9	6.2	12.6	8.3	22.0	36.1
44	23.1	16.5	36.3	39.6	16.8	7.4	6.7	12.8	9.3	23.5	39.3
46	24.9	17.1	38.2	42.0	18.9	8.0	7.2	13.1	10.4	25.1	42.9
48	27.0	17.8	40.4	44.8	21.1	8.6	7.7	13.3	11.7	27.0	46.9
50	29.5	18.5	42.9	48.0	23.8	9.2	8.3	13.6	13.2	29.3	51.3
52	32.6	19.3	46.0	51.8	27.1	9.9	8.9	13.9	15.0	32.0	56.2
54	36.4	20.1	49.7	56.5	31.1	10.7	9.6	14.3	17.3	35.4	61.8
56	41.2	21.1	54.4	62.3	36.3	11.5	10.3	14.7	20.1	39.7	68.2
58	47.8	22.2	60.5	70.0	43.2	12.4	11.1	15.1	24.0	45.5	75.8
60	57.3	23.5	69.2	80.7	53.1	13.5	12.1	15.5	29.5	53.7	85.1
62	72.5	25.0	82.9	97.5	68.9	14.8	13.2	16.1	38.2	66.8	96.9
64	103.1	27.1	109.6	130.2	100.2	16.3	14.6	16.8	55.6	92.8	113.5
66	230.5	30.5	217.8	261.0	228.9	18.8	16.8	17.9	126.9	199.9	143.6

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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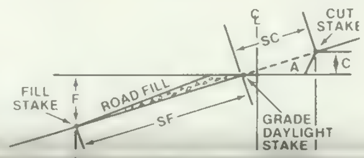
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.

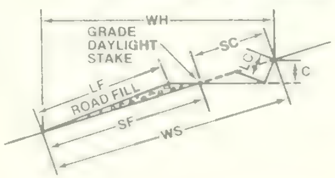
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 19 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.5	11.0	21.4	21.5	1.9	1.4	1.1	10.3	1.0	11.1	5.5
12	10.9	11.2	21.9	22.1	2.3	1.7	1.3	10.5	1.3	11.4	6.8
14	11.3	11.5	22.5	22.8	2.8	2.0	1.6	10.7	1.6	11.8	8.1
16	11.7	11.8	23.2	23.5	3.3	2.3	1.9	10.9	1.8	12.3	9.5
18	12.1	12.1	23.8	24.2	3.9	2.7	2.1	11.1	2.1	12.7	11.0
20	12.6	12.4	24.5	25.0	4.5	3.0	2.4	11.3	2.5	13.2	12.6
22	13.1	12.8	25.3	25.9	5.1	3.4	2.7	11.6	2.8	13.7	14.3
24	13.7	13.1	26.1	26.8	5.8	3.8	3.1	11.8	3.2	14.3	16.0
26	14.3	13.5	27.0	27.9	6.5	4.3	3.4	12.1	3.6	14.9	17.9
28	15.0	14.0	27.9	29.0	7.3	4.7	3.8	12.3	4.0	15.6	20.0
30	15.8	14.4	28.9	30.2	8.2	5.2	4.1	12.6	4.5	16.3	22.1
32	16.6	14.9	30.0	31.5	9.1	5.7	4.5	12.9	5.1	17.1	24.5
34	17.5	15.4	31.2	32.9	10.2	6.2	5.0	13.2	5.6	18.0	27.0
36	18.6	16.0	32.5	34.5	11.3	6.8	5.4	13.6	6.3	18.9	29.7
38	19.7	16.6	33.9	36.3	12.6	7.4	5.9	13.9	7.0	20.0	32.6
40	21.0	17.2	35.5	38.2	14.1	8.0	6.4	14.3	7.8	21.2	35.8
42	22.5	17.9	37.3	40.4	15.7	8.7	6.9	14.7	8.7	22.6	39.3
44	24.2	18.7	39.3	42.9	17.6	9.4	7.5	15.1	9.7	24.1	43.2
46	26.2	19.5	41.5	45.7	19.7	10.2	8.2	15.6	10.9	25.9	47.5
48	28.5	20.5	44.1	49.0	22.2	11.1	8.9	16.1	12.3	28.0	52.2
50	31.3	21.5	47.2	52.8	25.2	12.0	9.6	16.7	14.0	30.5	57.6
52	34.7	22.6	50.8	57.3	28.9	13.0	10.4	17.3	16.0	33.5	63.7
54	38.9	23.9	55.2	62.8	33.3	14.2	11.3	18.0	18.5	37.2	70.8
56	44.4	25.3	60.8	69.7	39.1	15.4	12.4	18.8	21.7	42.0	79.1
58	51.8	27.0	68.1	78.8	46.9	16.9	13.5	19.6	26.0	48.5	89.1
60	62.5	28.9	78.4	91.4	58.0	18.6	14.9	20.7	32.2	57.8	101.5
62	79.9	31.3	94.5	111.2	75.9	20.6	16.5	21.9	42.1	72.6	117.6
64	114.8	34.5	125.8	149.4	111.6	23.3	18.6	23.5	61.9	102.4	140.9
66	261.4	39.9	251.5	301.3	259.6	27.5	22.0	26.0	144.0	225.5	184.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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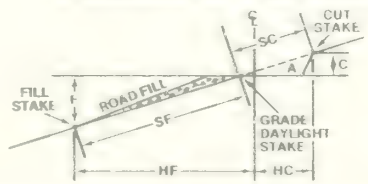
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL
A = END AREA OF CUT - SQ. FT.

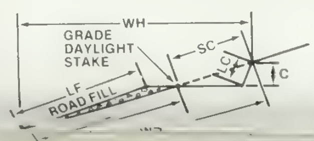
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 19 FEET

CUT SLOPE = 1.0 TO 1

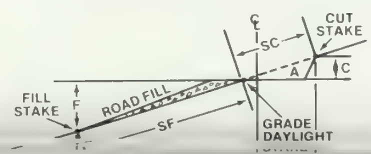
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.6	11.2	21.7	21.8	1.9	1.6	1.1	10.6	1.1	11.1	5.6
12	11.0	11.5	22.3	22.5	2.4	1.9	1.4	10.9	1.3	11.5	6.9
14	11.4	11.8	23.0	23.2	2.8	2.3	1.6	11.1	1.6	11.9	8.3
16	11.8	12.2	23.7	24.0	3.4	2.7	1.9	11.4	1.9	12.3	9.8
18	12.3	12.6	24.5	24.9	3.9	3.2	2.2	11.7	2.2	12.8	11.3
20	12.8	13.0	25.3	25.8	4.5	3.6	2.6	12.1	2.5	13.3	13.0
22	13.4	13.4	26.2	26.8	5.2	4.1	2.9	12.4	2.9	13.8	14.8
24	14.0	13.9	27.1	27.9	5.9	4.6	3.3	12.8	3.3	14.4	16.7
26	14.7	14.4	28.2	29.1	6.7	5.1	3.6	13.1	3.7	15.0	18.8
28	15.4	15.0	29.3	30.4	7.5	5.7	4.0	13.5	4.2	15.7	21.0
30	16.2	15.6	30.5	31.8	8.4	6.3	4.5	14.0	4.7	16.5	23.4
32	17.1	16.2	31.8	33.4	9.4	7.0	5.0	14.5	5.2	17.3	26.0
34	18.1	16.9	33.2	35.1	10.5	7.7	5.5	15.0	5.8	18.3	28.9
36	19.3	17.7	34.8	37.0	11.8	8.5	6.0	15.5	6.5	19.3	32.0
38	20.5	18.5	36.5	39.1	13.1	9.3	6.6	16.1	7.3	20.4	35.4
40	22.0	19.5	38.5	41.4	14.7	10.2	7.2	16.7	8.2	21.7	39.2
42	23.6	20.5	40.6	44.1	16.5	11.2	7.9	17.4	9.1	23.2	43.4
44	25.5	21.6	43.1	47.1	18.5	12.3	8.7	18.2	10.3	24.9	48.0
46	27.7	22.8	45.9	50.5	20.9	13.5	9.5	19.0	11.6	26.9	53.3
48	30.4	24.2	49.2	54.5	23.7	14.8	10.5	20.0	13.1	29.2	59.3
50	33.5	25.7	53.0	59.3	27.0	16.3	11.5	21.0	15.0	32.0	66.1
52	37.4	27.5	57.6	64.9	31.1	17.9	12.7	22.2	17.3	35.4	74.1
54	42.3	29.5	63.1	71.8	36.2	19.8	14.0	23.5	20.1	39.6	83.5
56	48.6	31.8	70.2	80.4	42.8	22.0	15.5	25.0	23.8	45.1	94.9
58	57.3	34.6	79.5	91.8	51.8	24.5	17.3	26.8	28.7	52.6	108.9
60	69.9	37.9	92.5	107.8	64.8	27.6	19.5	29.0	36.0	63.5	126.8
62	90.5	42.2	112.8	132.7	86.0	31.4	22.2	31.7	47.7	81.1	151.2
64	132.6	47.9	152.0	180.5	128.8	36.5	25.8	35.3	71.5	116.7	187.8
66	310.8	57.8	307.7	368.6	308.6	45.0	31.8	41.3	171.2	266.3	261.2

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.

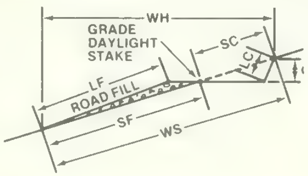
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 19 FEET

CUT SLOPE = 1.5 TO 1

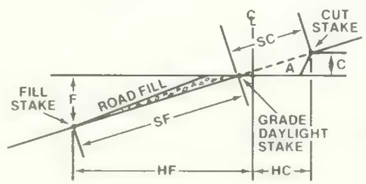
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.8	11.7	22.4	22.5	1.9	2.1	1.2	11.2	1.1	11.1	5.7
12	11.2	12.1	23.2	23.3	2.4	2.6	1.4	11.7	1.3	11.5	7.2
14	11.6	12.6	24.1	24.3	2.9	3.2	1.8	12.1	1.6	11.9	8.7
16	12.1	13.2	25.0	25.3	3.5	3.8	2.1	12.6	1.9	12.4	10.3
18	12.7	13.8	26.0	26.4	4.1	4.4	2.4	13.2	2.2	12.9	12.0
20	13.3	14.4	27.1	27.7	4.7	5.1	2.8	13.7	2.6	13.4	14.0
22	13.9	15.1	28.4	29.0	5.4	5.9	3.2	14.4	3.0	14.0	16.0
24	14.6	15.9	29.7	30.5	6.2	6.7	3.7	15.1	3.4	14.6	18.3
26	15.4	16.7	31.1	32.2	7.0	7.6	4.2	15.8	3.9	15.3	20.8
28	16.3	17.7	32.8	34.0	7.9	8.6	4.8	16.7	4.4	16.1	23.6
30	17.3	18.8	34.5	36.1	9.0	9.7	5.4	17.6	5.0	17.0	26.7
32	18.4	20.0	36.5	38.4	10.1	11.0	6.1	18.6	5.6	17.9	30.1
34	19.6	21.3	38.8	41.0	11.4	12.4	6.9	19.8	6.3	19.0	33.9
36	21.1	22.8	41.3	43.9	12.9	13.9	7.7	21.1	7.1	20.2	38.2
38	22.7	24.6	44.2	47.3	14.5	15.7	8.7	22.6	8.1	21.6	43.2
40	24.5	26.6	47.5	51.2	16.4	17.8	9.9	24.3	9.1	23.2	48.9
42	26.7	29.0	51.4	55.7	18.7	20.2	11.2	26.3	10.3	25.0	55.5
44	29.3	31.8	55.9	61.1	21.3	23.1	12.8	28.7	11.8	27.2	63.2
46	32.4	35.1	61.3	67.5	24.4	26.4	14.7	31.5	13.5	29.8	72.5
48	36.1	39.2	67.9	75.3	28.2	30.6	16.9	34.9	15.6	32.9	83.8
50	40.8	44.2	76.0	85.0	32.9	35.6	19.8	39.2	18.2	36.8	97.7
52	46.7	50.6	86.4	97.3	38.8	42.1	23.4	44.5	21.5	41.8	115.5
54	54.5	59.1	100.0	113.6	46.7	50.7	28.1	51.6	25.9	48.4	138.9
56	65.3	70.8	118.7	136.1	57.5	62.4	34.6	61.4	31.9	57.3	171.0
58	81.0	87.9	146.2	169.0	73.3	79.5	44.1	75.7	40.7	70.5	218.0
60	106.3	115.3	190.0	221.6	98.6	106.9	59.3	98.5	54.7	91.5	293.2
62	153.2	166.2	271.4	319.4	145.5	157.9	87.6	140.8	80.7	130.6	432.8
64	270.5	293.4	475.0	564.0	262.9	285.1	158.2	246.8	145.8	228.2	781.8
66	1092.0	1184.5	1900.0	2276.5	1084.4	1176.2	652.5	988.2	601.5	911.8	3225.0

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

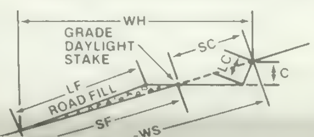
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 20 FEET

CUT SLOPE = VERTICAL

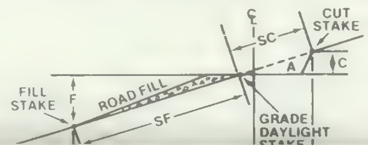
SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.9	10.9	21.6	21.7	1.9	1.1	1.1	10.0	1.1	11.6	5.8
12	11.2	11.0	22.0	22.2	2.4	1.3	1.3	10.0	1.3	12.0	7.1
14	11.5	11.1	22.4	22.6	2.9	1.5	1.5	10.0	1.6	12.4	8.5
16	11.9	11.2	22.8	23.1	3.4	1.8	1.8	10.0	1.9	12.8	9.8
18	12.3	11.4	23.3	23.6	3.9	2.0	2.0	10.0	2.2	13.3	11.3
20	12.7	11.5	23.7	24.2	4.5	2.3	2.3	10.0	2.5	13.7	12.7
22	13.1	11.7	24.2	24.8	5.1	2.5	2.5	10.0	2.8	14.2	14.3
24	13.6	11.8	24.8	25.5	5.7	2.8	2.8	10.0	3.2	14.8	15.9
26	14.2	12.0	25.4	26.2	6.4	3.0	3.0	10.0	3.6	15.4	17.6
28	14.8	12.2	26.0	27.0	7.2	3.3	3.3	10.0	4.0	16.0	19.3
30	15.4	12.4	26.6	27.8	8.0	3.6	3.6	10.0	4.4	16.6	21.2
32	16.1	12.6	27.4	28.7	8.9	3.8	3.8	10.0	4.9	17.4	23.1
34	16.9	12.8	28.2	29.7	9.8	4.1	4.1	10.0	5.4	18.2	25.1
36	17.8	13.1	29.0	30.9	10.9	4.4	4.4	10.0	6.0	19.0	27.3
38	18.7	13.3	30.0	32.1	12.0	4.7	4.7	10.0	6.7	20.0	29.5
40	19.8	13.6	31.0	33.4	13.3	5.1	5.1	10.0	7.4	21.0	31.9
42	21.1	13.9	32.2	35.0	14.7	5.4	5.4	10.0	8.2	22.2	34.5
44	22.5	14.2	33.6	36.7	16.3	5.7	5.7	10.0	9.0	23.6	37.2
46	24.1	14.5	35.1	38.6	18.1	6.1	6.1	10.0	10.1	25.1	40.2
48	26.0	14.9	36.9	40.9	20.3	6.5	6.5	10.0	11.2	26.9	43.4
50	28.2	15.3	38.9	43.5	22.8	6.8	6.8	10.0	12.6	28.9	46.9
52	30.9	15.7	41.4	46.7	25.7	7.3	7.3	10.0	14.3	31.4	50.7
54	34.3	16.2	44.4	50.5	29.4	7.7	7.7	10.0	16.3	34.4	55.0
56	38.6	16.7	48.3	55.3	34.0	8.2	8.2	10.0	18.9	38.3	59.8
58	44.4	17.4	53.4	61.7	41.1	8.7	8.7	10.0	22.3	43.4	65.3
60	52.7	18.1	60.6	70.7	48.8	9.3	9.3	10.0	27.1	50.6	71.9
62	65.9	18.9	72.1	84.8	62.6	10.0	10.0	10.0	34.7	62.1	80.1
64	92.4	20.0	94.7	112.5	89.8	10.8	10.8	10.0	49.8	84.7	91.2
66	202.3	21.9	187.1	224.2	200.9	12.1	12.1	10.0	111.4	177.1	110.7

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.

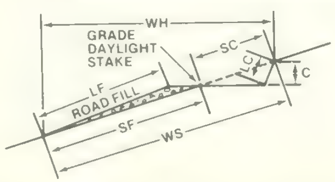
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 20 FEET

CUT SLOPE = .10 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.9	10.9	21.7	21.8	2.0	1.1	1.1	10.1	1.1	11.6	5.9
12	11.2	11.1	22.1	22.3	2.4	1.3	1.3	10.1	1.3	12.0	7.2
14	11.6	11.2	22.6	22.8	2.9	1.6	1.6	10.2	1.6	12.4	8.5
16	11.9	11.4	23.0	23.3	3.4	1.8	1.8	10.2	1.9	12.8	9.9
18	12.3	11.5	23.5	23.9	3.9	2.1	2.0	10.2	2.2	13.3	11.4
20	12.8	11.7	24.0	24.5	4.5	2.3	2.3	10.2	2.5	13.8	12.9
22	13.2	11.9	24.5	25.1	5.1	2.6	2.6	10.3	2.8	14.3	14.5
24	13.7	12.1	25.1	25.8	5.8	2.8	2.8	10.3	3.2	14.8	16.1
26	14.3	12.3	25.7	26.6	6.5	3.1	3.1	10.3	3.6	15.4	17.8
28	14.9	12.5	26.4	27.4	7.2	3.4	3.4	10.3	4.0	16.0	19.7
30	15.6	12.7	27.1	28.3	8.1	3.7	3.7	10.4	4.5	16.7	21.5
32	16.3	12.9	27.8	29.2	8.9	4.0	3.9	10.4	5.0	17.4	23.5
34	17.1	13.2	28.7	30.3	9.9	4.3	4.2	10.4	5.5	18.3	25.6
36	18.0	13.5	29.6	31.5	11.0	4.6	4.6	10.5	6.1	19.1	27.9
38	19.0	13.8	30.6	32.7	12.2	4.9	4.9	10.5	6.7	20.1	30.2
40	20.1	14.1	31.7	34.2	13.5	5.3	5.2	10.5	7.5	21.2	32.8
42	21.4	14.4	33.0	35.8	14.9	5.6	5.6	10.6	8.3	22.4	35.4
44	22.8	14.7	34.4	37.5	16.6	6.0	5.9	10.6	9.2	23.8	38.3
46	24.5	15.1	36.0	39.6	18.4	6.4	6.3	10.6	10.2	25.3	41.4
48	26.4	15.5	37.8	41.9	20.6	6.8	6.7	10.7	11.4	27.1	44.8
50	28.7	16.0	40.0	44.7	23.2	7.2	7.1	10.7	12.8	29.3	48.5
52	31.5	16.5	42.6	48.0	26.2	7.6	7.6	10.8	14.5	31.8	52.6
54	35.0	17.0	45.7	52.0	30.0	8.1	8.1	10.8	16.6	34.9	57.2
56	39.4	17.6	49.7	57.0	34.7	8.6	8.6	10.9	19.3	38.9	62.3
58	45.4	18.3	55.1	63.7	41.0	9.2	9.2	10.9	22.8	44.1	68.3
60	53.9	19.1	62.6	73.0	50.0	9.9	9.8	11.0	27.7	51.6	75.5
62	67.6	20.0	74.5	87.7	64.2	10.6	10.6	11.1	35.6	63.5	84.4
64	95.0	21.3	98.0	116.3	92.3	11.5	11.5	11.1	51.2	86.8	96.5
66	208.7	23.4	193.7	232.1	207.2	13.0	12.9	11.3	115.0	182.4	117.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



SF = SLOPE DIST. TO TOE FILL
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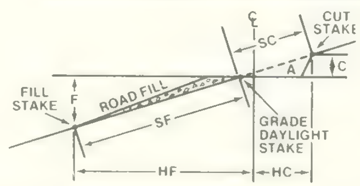
WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
LF = LENGTH OF FILL SLOPE
LC = LENGTH OF CUT SLOPE
C = CUT HEIGHT

ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

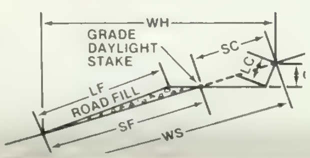
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 20 FEET

CUT SLOPE = .25 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	10.9	11.1	21.9	22.0	2.0	1.1	1.1	10.3	1.1	11.6	5.9
12	11.3	11.2	22.3	22.5	2.4	1.4	1.3	10.3	1.3	12.0	7.2
14	11.6	11.4	22.8	23.0	2.9	1.6	1.6	10.4	1.6	12.4	8.6
16	12.0	11.6	23.3	23.6	3.4	1.9	1.8	10.5	1.9	12.8	10.1
18	12.4	11.8	23.8	24.2	4.0	2.2	2.1	10.5	2.2	13.3	11.6
20	12.9	12.0	24.4	24.9	4.6	2.4	2.4	10.6	2.5	13.8	13.1
22	13.4	12.2	25.0	25.6	5.2	2.7	2.6	10.7	2.9	14.3	14.8
24	13.9	12.4	25.6	26.3	5.8	3.0	2.9	10.7	3.2	14.9	16.5
26	14.5	12.7	26.3	27.1	6.6	3.3	3.2	10.8	3.6	15.5	18.3
28	15.1	12.9	27.0	28.0	7.3	3.6	3.5	10.9	4.1	16.1	20.2
30	15.8	13.2	27.7	29.0	8.2	3.9	3.8	10.9	4.5	16.8	22.2
32	16.5	13.5	28.6	30.0	9.1	4.2	4.1	11.0	5.0	17.6	24.3
34	17.4	13.8	29.5	31.2	10.1	4.6	4.4	11.1	5.6	18.4	26.5
36	18.3	14.1	30.5	32.4	11.2	4.9	4.8	11.2	6.2	19.3	28.9
38	19.3	14.5	31.6	33.8	12.4	5.3	5.1	11.3	6.9	20.3	31.4
40	20.5	14.8	32.8	35.3	13.7	5.7	5.5	11.4	7.6	21.4	34.1
42	21.8	15.2	34.1	37.0	15.2	6.1	5.9	11.5	8.4	22.7	37.0
44	23.3	15.6	35.7	39.0	16.9	6.5	6.3	11.6	9.4	24.1	40.1
46	25.1	16.1	37.4	41.2	18.9	6.9	6.7	11.7	10.5	25.7	43.5
48	27.1	16.6	39.4	43.7	21.1	7.4	7.2	11.8	11.7	27.6	47.2
50	29.5	17.1	41.7	46.6	23.8	7.9	7.7	11.9	13.2	29.8	51.3
52	32.5	17.7	44.5	50.2	27.0	8.4	8.2	12.0	15.0	32.5	55.8
54	36.1	18.3	47.9	54.4	30.9	9.0	8.7	12.2	17.2	35.7	60.9
56	40.8	19.1	52.2	59.8	35.9	9.6	9.3	12.3	19.9	39.9	66.7
58	47.0	19.9	57.9	66.9	42.5	10.3	10.0	12.5	23.6	45.4	73.4
60	56.0	20.8	65.9	76.9	52.0	11.1	10.7	12.7	28.8	53.2	81.5
62	70.5	22.0	78.6	92.5	67.0	12.0	11.6	12.9	37.1	65.7	91.7
64	99.4	23.5	103.6	123.0	96.6	13.1	12.7	13.2	53.6	90.4	105.6
66	219.6	26.1	205.1	245.7	218.1	14.8	14.4	13.6	121.0	191.5	130.4

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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WH = TOT. WIDTH DISTURB. HOR.
WS = TOT. WIDTH DISTURB. SLOPE
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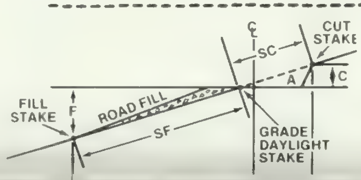
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



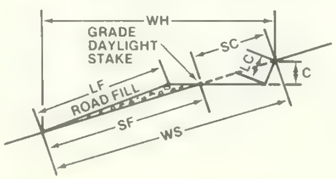
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 20 FEET

CUT SLOPE = .50 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	11.0	11.3	22.2	22.3	2.0	1.3	1.1	10.6	1.1	11.6	6.0
12	11.4	11.5	22.7	22.9	2.4	1.5	1.4	10.7	1.4	12.0	7.4
14	11.7	11.7	23.3	23.5	2.9	1.8	1.6	10.8	1.6	12.4	8.8
16	12.2	12.0	23.8	24.1	3.5	2.1	1.9	10.9	1.9	12.9	10.3
18	12.6	12.2	24.4	24.8	4.0	2.4	2.2	11.1	2.2	13.3	11.9
20	13.1	12.5	25.1	25.6	4.6	2.7	2.5	11.2	2.6	13.8	13.5
22	13.6	12.8	25.8	26.4	5.3	3.1	2.7	11.4	2.9	14.4	15.3
24	14.1	13.1	26.5	27.2	6.0	3.4	3.1	11.5	3.3	15.0	17.1
26	14.8	13.4	27.3	28.2	6.7	3.8	3.4	11.7	3.7	15.6	19.0
28	15.4	13.7	28.1	29.2	7.5	4.1	3.7	11.9	4.2	16.2	21.1
30	16.2	14.1	29.0	30.3	8.4	4.5	4.1	12.0	4.6	17.0	23.3
32	17.0	14.5	30.0	31.5	9.3	4.9	4.4	12.2	5.2	17.8	25.6
34	17.9	14.9	31.0	32.8	10.4	5.4	4.8	12.4	5.8	18.6	28.1
36	18.9	15.3	32.2	34.2	11.5	5.8	5.2	12.6	6.4	19.6	30.7
38	20.0	15.8	33.5	35.8	12.8	6.3	5.6	12.8	7.1	20.7	33.6
40	21.3	16.3	34.9	37.6	14.2	6.8	6.1	13.0	7.9	21.8	36.6
42	22.7	16.8	36.4	39.5	15.8	7.3	6.5	13.3	8.8	23.2	40.0
44	24.3	17.4	38.2	41.7	17.7	7.8	7.0	13.5	9.8	24.7	43.6
46	26.2	18.0	40.2	44.2	19.7	8.4	7.5	13.8	11.0	26.4	47.6
48	28.4	18.7	42.5	47.1	22.2	9.1	8.1	14.0	12.3	28.5	51.9
50	31.1	19.5	45.2	50.5	25.1	9.7	8.7	14.4	13.9	30.8	56.8
52	34.3	20.3	48.4	54.5	28.5	10.5	9.4	14.7	15.8	33.7	62.2
54	38.3	21.2	52.3	59.4	32.8	11.2	10.1	15.0	18.2	37.3	68.4
56	43.4	22.2	57.2	65.6	38.2	12.1	10.8	15.4	21.2	41.8	75.6
58	50.3	23.4	63.7	73.7	45.5	13.1	11.7	15.9	25.2	47.9	84.0
60	60.3	24.7	72.9	85.0	55.9	14.2	12.7	16.4	31.0	56.5	94.3
62	76.3	26.4	87.3	102.7	72.5	15.5	13.9	16.9	40.2	70.3	107.4
64	108.5	28.5	115.4	137.0	105.4	17.2	15.4	17.7	58.5	97.7	125.7
66	242.6	32.1	229.3	274.7	240.9	19.8	17.7	18.9	133.6	210.4	159.1

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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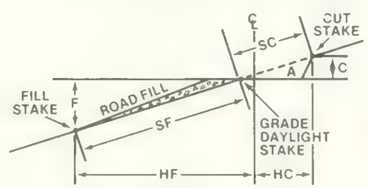
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

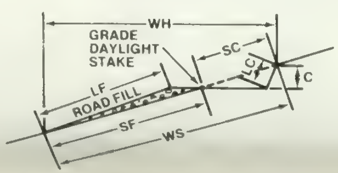
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 20 FEET

CUT SLOPE = .75 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	11.1	11.5	22.5	22.6	2.0	1.4	1.1	10.9	1.1	11.7	6.1
12	11.5	11.8	23.1	23.3	2.5	1.8	1.4	11.1	1.4	12.0	7.5
14	11.9	12.1	23.7	24.0	3.0	2.1	1.7	11.3	1.6	12.5	9.0
16	12.3	12.4	24.4	24.7	3.5	2.4	2.0	11.5	1.9	12.9	10.5
18	12.8	12.7	25.1	25.5	4.1	2.8	2.3	11.7	2.3	13.4	12.2
20	13.3	13.1	25.8	26.3	4.7	3.2	2.6	11.9	2.6	13.9	14.0
22	13.8	13.4	26.6	27.3	5.4	3.6	2.9	12.2	3.0	14.5	15.8
24	14.4	13.8	27.5	28.2	6.1	4.0	3.2	12.4	3.4	15.0	17.8
26	15.1	14.2	28.4	29.3	6.8	4.5	3.6	12.7	3.8	15.7	19.9
28	15.8	14.7	29.4	30.5	7.7	5.0	4.0	13.0	4.3	16.4	22.1
30	16.6	15.2	30.4	31.8	8.6	5.4	4.4	13.3	4.8	17.2	24.5
32	17.5	15.7	31.6	33.1	9.6	6.0	4.8	13.6	5.3	18.0	27.1
34	18.4	16.2	32.8	34.7	10.7	6.5	5.2	13.9	5.9	18.9	29.9
36	19.5	16.8	34.2	36.3	11.9	7.1	5.7	14.3	6.6	19.9	32.9
38	20.7	17.4	35.7	38.2	13.3	7.7	6.2	14.6	7.4	21.1	36.1
40	22.1	18.1	37.4	40.3	14.8	8.4	6.7	15.1	8.2	22.3	39.7
42	23.7	18.9	39.2	42.6	16.5	9.1	7.3	15.5	9.2	23.8	43.6
44	25.5	19.7	41.3	45.2	18.5	9.9	7.9	15.9	10.3	25.4	47.9
46	27.6	20.6	43.7	48.1	20.8	10.7	8.6	16.4	11.5	27.3	52.6
48	30.0	21.5	46.5	51.5	23.4	11.6	9.3	17.0	13.0	29.5	57.9
50	32.9	22.6	49.7	55.5	26.6	12.6	10.1	17.6	14.7	32.1	63.8
52	36.5	23.8	53.5	60.3	30.4	13.7	11.0	18.2	16.8	35.3	70.6
54	41.0	25.1	58.2	66.1	35.1	14.9	11.9	19.0	19.5	39.2	78.5
56	46.7	26.6	64.0	73.4	41.2	16.3	13.0	19.8	22.8	44.3	87.7
58	54.5	28.4	71.7	82.9	49.3	17.8	14.2	20.7	27.4	51.0	98.7
60	65.8	30.4	82.5	96.3	61.0	19.6	15.7	21.7	33.9	60.8	112.4
62	84.1	33.0	99.5	117.1	79.9	21.7	17.4	23.0	44.3	76.5	130.3
64	120.9	36.4	132.4	157.2	117.5	24.5	19.6	24.7	65.2	107.7	156.1
66	275.2	42.0	264.7	317.2	273.3	28.9	23.1	27.4	151.6	237.4	204.8

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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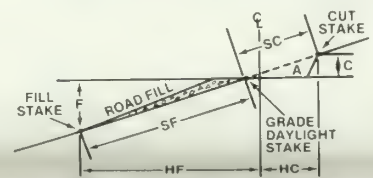
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



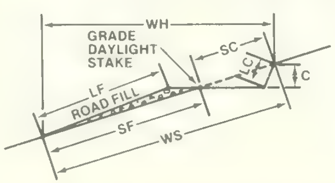
SF = SLOPE DIST. TO TOE FILL
SC = SLOPE DIST. TO TOP CUT
C = CUT HEIGHT
HC = HOR. DIST. CUT STAKE TO CL.
F = FILL HEIGHT
HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

ROAD WIDTH = 20 FEET

CUT SLOPE = 1.0 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	11.2	11.8	22.8	23.0	2.0	1.7	1.2	11.2	1.1	11.7	6.2
12	11.6	12.1	23.5	23.7	2.5	2.0	1.4	11.4	1.4	12.1	7.6
14	12.0	12.5	24.2	24.5	3.0	2.4	1.7	11.7	1.7	12.5	9.2
16	12.5	12.8	25.0	25.3	3.5	2.9	2.0	12.0	2.0	13.0	10.8
18	13.0	13.3	25.8	26.2	4.1	3.3	2.3	12.3	2.3	13.4	12.6
20	13.5	13.7	26.7	27.2	4.8	3.8	2.7	12.7	2.6	14.0	14.4
22	14.1	14.2	27.6	28.2	5.5	4.3	3.0	13.0	3.0	14.5	16.4
24	14.7	14.7	28.6	29.4	6.2	4.8	3.4	13.4	3.4	15.2	18.5
26	15.4	15.2	29.7	30.6	7.0	5.4	3.8	13.8	3.9	15.8	20.8
28	16.2	15.8	30.8	32.0	7.9	6.0	4.3	14.3	4.4	16.6	23.3
30	17.1	16.4	32.1	33.5	8.8	6.7	4.7	14.7	4.9	17.4	26.0
32	18.0	17.1	33.5	35.1	9.9	7.4	5.2	15.2	5.5	18.2	28.8
34	19.1	17.8	35.0	36.9	11.1	8.1	5.7	15.7	6.1	19.2	32.0
36	20.3	18.6	36.6	38.9	12.4	8.9	6.3	16.3	6.9	20.3	35.4
38	21.6	19.5	38.4	41.1	13.8	9.8	6.9	16.9	7.7	21.5	39.2
40	23.1	20.5	40.5	43.6	15.5	10.8	7.6	17.6	8.6	22.9	43.4
42	24.9	21.5	42.8	46.4	17.4	11.8	8.3	18.3	9.6	24.4	48.0
44	26.9	22.7	45.4	49.6	19.5	12.9	9.1	19.1	10.8	26.2	53.2
46	29.2	24.0	48.3	53.2	22.0	14.2	10.0	20.0	12.2	28.3	59.1
48	32.0	25.4	51.8	57.4	24.9	15.6	11.0	21.0	13.8	30.8	65.7
50	35.3	27.1	55.8	62.4	28.5	17.1	12.1	22.1	15.8	33.7	73.3
52	39.4	28.9	60.6	68.3	32.8	18.9	13.3	23.3	18.2	37.3	82.1
54	44.5	31.0	66.5	75.5	38.1	20.8	14.7	24.7	21.1	41.7	92.6
56	51.2	33.5	73.9	84.7	45.1	23.1	16.4	26.4	25.0	47.5	105.1
58	60.3	36.4	83.6	96.7	54.5	25.8	18.3	28.3	30.3	55.4	120.7
60	73.6	39.9	97.3	113.5	68.3	29.0	20.5	30.5	37.9	66.8	140.6
62	95.3	44.4	118.7	139.7	90.5	33.1	23.4	33.4	50.2	85.3	167.5
64	139.5	50.5	160.0	190.0	135.6	38.5	27.2	37.2	75.2	122.8	208.0
66	327.2	60.9	323.8	388.0	324.9	47.4	33.5	43.5	180.2	280.3	289.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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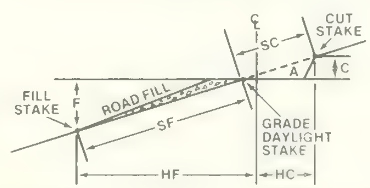
ROAD DIMENSIONS FOR SLOPE STAKING AND END AREAS



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HF = HOR. DIST. FILL STAKE TO CL.
A = END AREA OF CUT - SQ. FT.

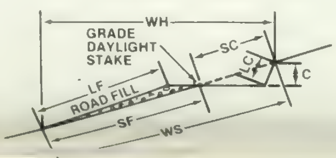
ROAD GEOMETRY DATA USING A 1.5 TO 1 FILL SLOPE

ROAD WIDTH = 20 FEET

CUT SLOPE = 1.5 TO 1

SLOPE PERCENT	SF	SC	WH	WS	LF	LC	C	HC	F	HF	A
10	11.3	12.3	23.5	23.6	2.0	2.2	1.2	11.8	1.1	11.7	6.4
12	11.8	12.8	24.4	24.6	2.5	2.7	1.5	12.3	1.4	12.1	7.9
14	12.3	13.3	25.3	25.6	3.1	3.3	1.8	12.8	1.7	12.6	9.6
16	12.8	13.9	26.3	26.7	3.6	3.9	2.2	13.3	2.0	13.0	11.4
18	13.4	14.5	27.4	27.8	4.3	4.6	2.6	13.8	2.4	13.5	13.4
20	14.0	15.2	28.6	29.1	4.9	5.4	3.0	14.5	2.7	14.1	15.5
22	14.7	15.9	29.9	30.6	5.7	6.2	3.4	15.1	3.2	14.7	17.8
24	15.4	16.7	31.3	32.1	6.5	7.0	3.9	15.9	3.6	15.4	20.3
26	16.3	17.6	32.8	33.9	7.4	8.0	4.4	16.7	4.1	16.1	23.1
28	17.2	18.6	34.5	35.8	8.3	9.1	5.0	17.5	4.6	16.9	26.1
30	18.2	19.8	36.4	38.0	9.4	10.2	5.7	18.5	5.2	17.8	29.5
32	19.4	21.0	38.5	40.4	10.6	11.5	6.4	19.6	5.9	18.9	33.3
34	20.7	22.4	40.8	43.1	12.0	13.0	7.2	20.8	6.7	20.0	37.6
36	22.2	24.0	43.5	46.2	13.5	14.7	8.1	22.2	7.5	21.3	42.4
38	23.9	25.9	46.5	49.8	15.3	16.6	9.2	23.8	8.5	22.7	47.8
40	25.8	28.0	50.0	53.9	17.3	18.8	10.4	25.6	9.6	24.4	54.1
42	28.1	30.5	54.1	58.6	19.6	21.3	11.8	27.7	10.9	26.3	61.5
44	30.8	33.4	58.8	64.3	22.4	24.3	13.5	30.2	12.4	28.6	70.1
46	34.1	36.9	64.5	71.0	25.7	27.8	15.4	33.2	14.2	31.4	80.3
48	38.0	41.2	71.4	79.2	29.6	32.2	17.8	36.8	16.4	34.7	92.8
50	42.9	46.5	80.0	89.4	34.6	37.5	20.8	41.2	19.2	38.8	108.3
52	49.2	53.3	90.9	102.5	40.9	44.3	24.6	46.9	22.7	44.0	128.0
54	57.4	62.2	105.3	119.6	49.2	53.3	29.6	54.4	27.3	50.9	153.9
56	68.7	74.5	125.0	143.3	60.5	65.7	36.4	64.6	33.6	60.4	189.5
58	85.3	92.5	153.8	177.9	77.2	83.7	46.4	79.6	42.8	74.2	241.6
60	111.9	121.4	200.0	233.2	103.8	112.6	62.4	103.7	57.6	96.3	324.9
62	161.3	174.9	285.7	336.2	153.2	166.2	92.2	148.3	85.0	137.5	479.6
64	284.8	308.9	500.0	593.6	276.7	300.2	166.5	259.7	153.5	240.3	866.3
66	1149.5	1246.8	2000.0	2396.3	1141.5	1238.1	686.8	1040.2	633.2	959.8	3573.5

ROAD DIMENSIONS FOR WATERSHED MANAGEMENT



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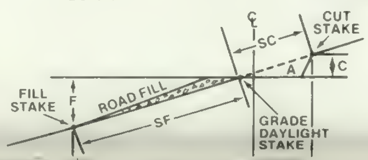

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Megahan, Walter F.
1976. Tables of geometry for low-standard roads for watershed management considerations, slope staking, and end areas. USDA For. Serv. Gen. Tech. Rep. INT-32, 104 p. Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.

Tables provide various dimensions for low-standard roads built with a "balanced" construction technique. In addition to assisting in slope staking and in the determination of excavation volumes, the information offers a means of evaluating potential watershed impacts of road construction and aids in the planning of appropriate erosion-control measures. The material is applicable to both the road location and design phases of road construction.

OXFORD: 116; 116.5; 116.65; 383; 686.3
KEYWORDS: watershed management, road erosion, road construction, road prism, road design, erosion control, sedimentation

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

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USDA Forest Service General Technical Report INT-33
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

ABSTRACT

Includes 590 references to published material on Pinus ponderosa Laws. issued from 1971 through 1975. Subject index is based on the Oxford System for forestry.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

USDA Forest Service
General Technical Report INT-33
March 1977

PONDEROSA PINE BIBLIOGRAPHY III: 1971 THROUGH 1975

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FOREWORD

Ponderosa pine (Pinus ponderosa Laws.) is an important softwood species in the United States. Because of its extensive range and economic importance, considerable research has been conducted on this valuable species. This supplement updates through 1975 the 1967 bibliography[1] and supplement[2] compiled by Axelton at the Boise research laboratory of the Intermountain Forest and Range Experiment Station.

References have been limited to published material. A few foreign publications have been included, although a search of foreign literature was not made. Popular-type articles have been omitted.

The subject index follows the Oxford System of classification for forestry, except in a few cases where the index was slightly modified to simplify the presentation of subject matter. Articles were indexed under what was considered the principal topic, but no reference was listed under more than three subjects. Material pertaining to forest pests, although dealing with both damage and control, was indexed under "Damage." Only articles dealing primarily with control were indexed under "Protection."

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Forest Service series resear publications are preceded by tw three letters identifying the o nating unit. Such abbreviation this bibliography and the names addresses of the originating un are:

FPL
Forest Products Laboratory
P.O. Box 5130, Madison, Wis. 53

FS
Forest Service
P.O. Box 2417, Washington, D.C.

INT
Intermountain Forest and Range
Experiment Station
507 - 25th Street, Ogden, Utah

PNW
Pacific Northwest Forest and Ra
Experiment Station
P.O. Box 3141, Portland, Oreg.

PSW
Pacific Southwest Forest and Ra
Experiment Station
P.O. Box 245, Berkeley, Calif.

RM
Rocky Mountain Forest and Range
Experiment Station
240 West Prospect Street
Fort Collins, Colo. 80521

WO
Washington Office
Forest Service
U.S. Department of Agriculture
P.O. Box 2417
Washington, D.C. 20250

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☆U.S. GOVERNMENT PRINTING OFFICE: 1977-0-777-023-32

Axelton, Elvera A. (Compiler).
1977. Ponderosa pine bibliography III: 1971 through 1975. USDA For. Serv. Gen. Tech. Rep. INT-33, 54 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

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